

12 ALAMAGAN

12.1 Introduction

The island of Alamagan is located at $\sim 17^{\circ}36' \text{ N}$, $145^{\circ}50' \text{ E}$ in the middle of the Mariana Arc, 52 km south of Pagan and 32 km north of Guguan. This island is $\sim 4 \text{ km}$ wide and 4.8 km long, with a land area of 12.96 km^2 (Fig. 12.1a). As with all of the other northern islands in the Mariana Archipelago, Alamagan is a volcanic peak, the emergent tip of a much larger, mainly submarine volcano that is $\sim 15 \text{ km}$ in diameter. The highest elevation of this island is 744 m on the rim of its 350-m deep crater (Fig. 12.1b). The remainder of this island is typically characterized by steep slopes, with flatter areas extending north and south that result from lava flows. Historically, Alamagan has been inhabited by small human populations, mainly within 2 villages, including Songsong on the southern side of this island. In 2000, a homestead site was observed at Patida camp on the northwestern side of this island (Cruz et al. 2000).

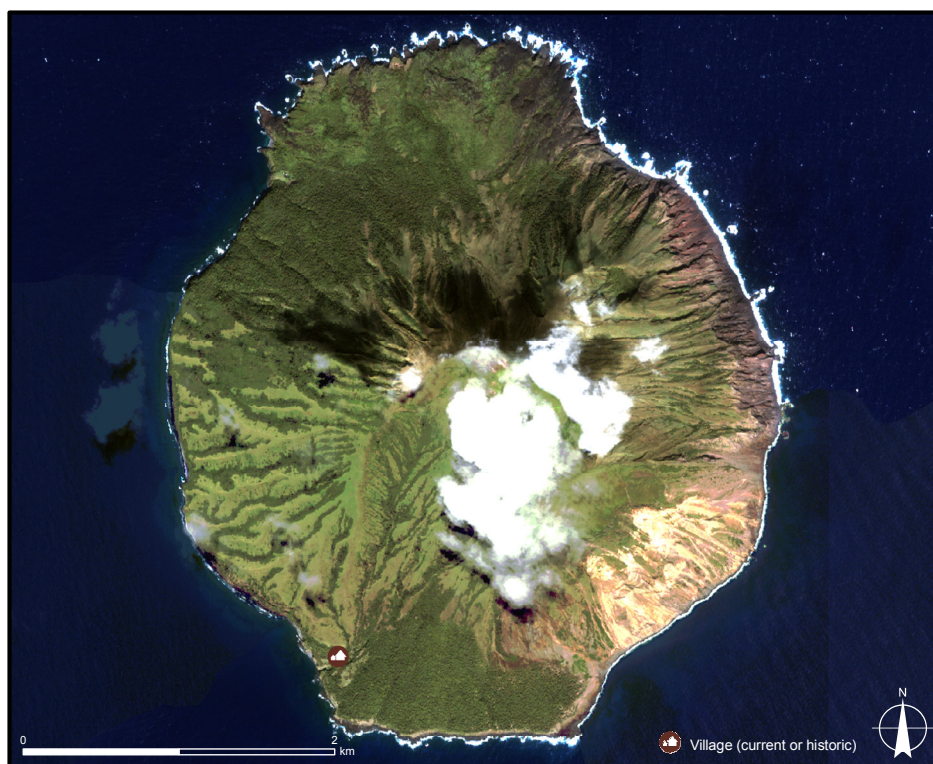


Figure 12.1a. Satellite image of Alamagan (IKONOS Carterra Geo Data, 2003).



Figure 12.1b. Alamagan viewed from the northeast, as seen from the NOAA Ship *Hi'ialakai* in 2007. NOAA photo

12.1.1 History and Demographics

Evidence of historic occupation by Chamorro people was discovered by Georg Fritz, the first German administrator of the Northern Mariana Islands, when visiting this island in 1901 (Spennemann 2006). This island has been sporadically populated in fairly small numbers, varying with changes in economic factors and the risk posed by possible eruptions from Alamagan or other nearby volcanoes. During the early 1900s, a populated Alamagan was leased by the Germany to the Pagan Gesellschaft, a trading organization, for copra production (Spennemann 1999b). Copra production was the mainstay of the German economy in the Marshall Islands and in much of Micronesia during this time (Spennemann 1999b). A series of typhoons between 1904 and 1907 resulted in a 50% reduction in copra production (Spennemann 1999b).

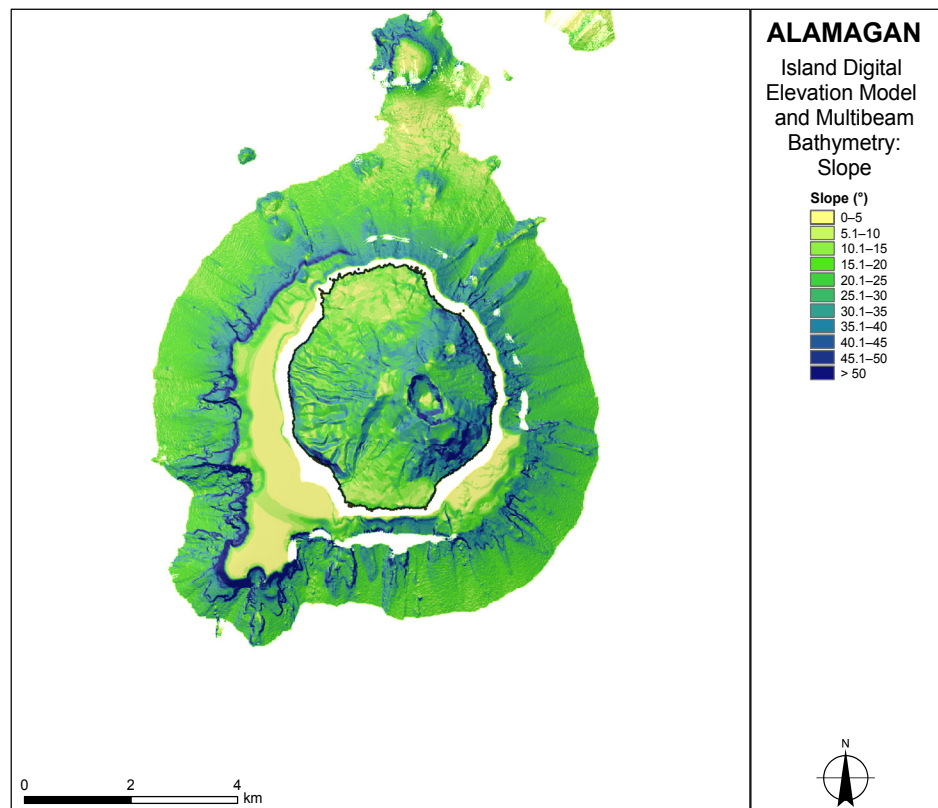
Copra production and inhabitation of this island continued, although a shortage of copra on Alamagan in 1962 reduced the number of residents to the extent that it was necessary to close the Alamagan Public Elementary School because of a lack of students (University of Hawaii 2009). Since then, residents of Alamagan have been evacuated numerous times, including in 2003, because of the threat of volcanic eruptions (Siebert and Simkin 2002–). Alamagan is part of the Northern Islands Municipality of the Commonwealth of the Northern Mariana Islands (CNMI). For this municipality, the 2000 U.S. Census recorded an official population of 6 persons, but the 2010 U.S. Census recorded no persons (U.S. Bureau of the Census 2003, 2011a).

Alamagan is one the islands where land could be designated for village and homesteading programs. The *Northern Islands Homestead Act of 2008*, which was signed into law by the Governor of the CNMI in January 2010, recognizes that residents of the “islands north of Saipan” have no formal homesteads, allows residents to have agricultural lots and facilities, encourages resettlement by former residents, and initiates and promotes economic development. This legislation, CNMI Public Law 16-50, may increase the population on Alamagan in coming years.

12.1.2 Geography

Bandeera Peak, the volcano located east of the center of this steeply sloping island, has a summit crater that is ~950 m by 600 m and 350-m deep. The steepest slopes of this volcano are east of this crater (Fig. 12.1.2a), and steep slopes of bare lava lie southeast of this crater (University of California San Diego 2009). The slopes on the west side of Alamagan are cut by deep gorges and are more gradual here than on other sides (University of California San Diego 2009). The north-

Figure 12.1.2a. Combined slope map using the digital elevation model and bathymetric data for Alamagan (grid cell size: 10 m).



ern and southern coasts of Alamagan have been extended by lava flows that have created low-angle lava platforms (Fig. 12.1.2b). The southwestern flank of Alamagan is cut by a graben, an elongated (1.6×1 km), relatively depressed crustal unit bounded by faults on both sides (Siebert and Simkin 2002–). No beaches were found around Alamagan, and this island is surrounded by sea cliffs.

The last known eruption at Alamagan, dated from pyroclastic flow deposits, occurred at 1077 ± 87 years BP or \sim AD 870 (Moore and Trusdell 1993; Siebert and Simkin 2002–); however, active steam fumaroles were observed during scientific surveys conducted on this island in 2000 (Cruz et al. 2000). The first known eruption of a volcano in the Mariana Archipelago, based on radiocarbon dating, was of Alamagan in AD 540 (Siebert and Simkin 2002–).

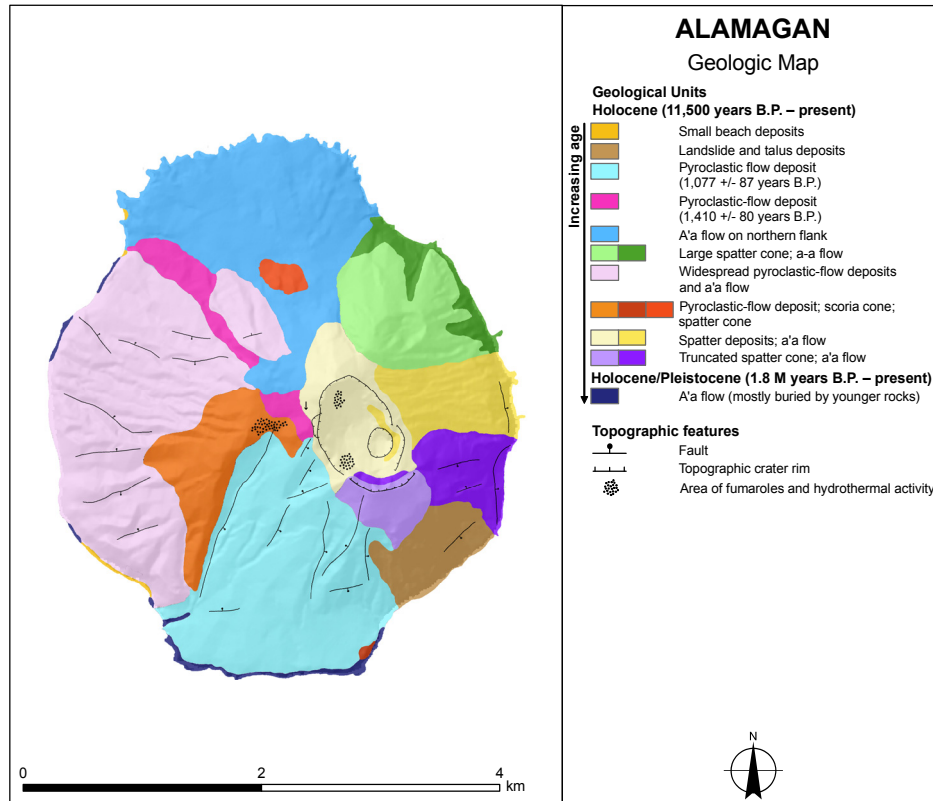
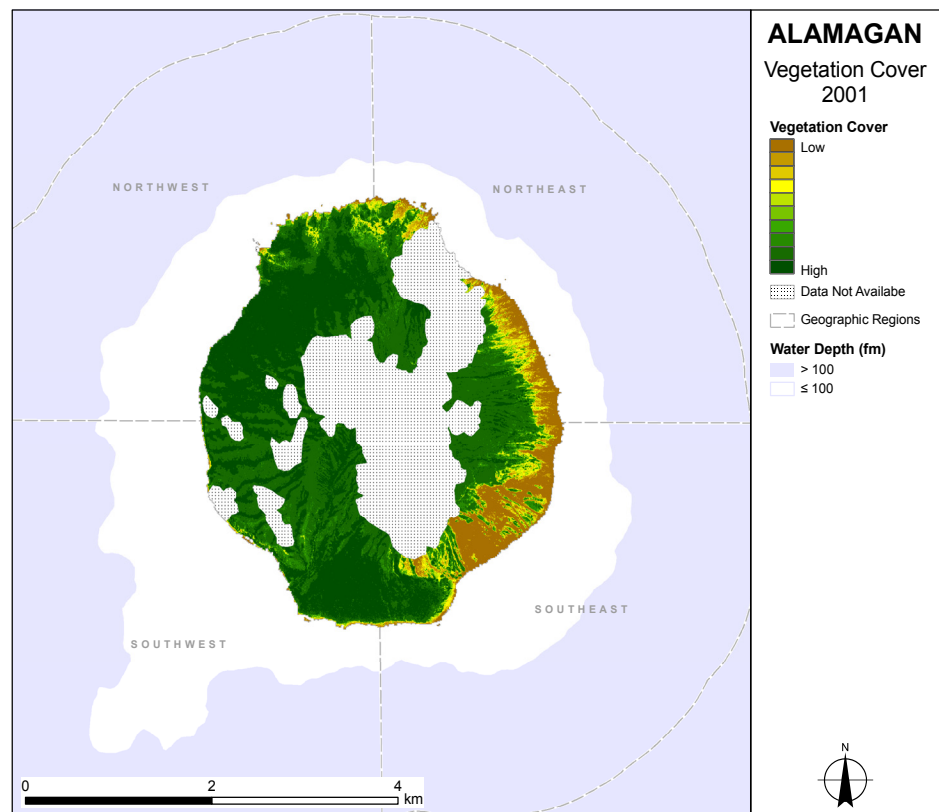


Figure 12.1.2b. Geologic map of Alamagan (adapted from Moore and Trusdell 1993).

The pattern of vegetation on Alamagan is typical of the less volcanically active, northern volcanic islands of the Mariana Archipelago. Sword grass (*Miscanthus floridulus*) dominates the upper (elevations > 150 m) ash slopes of this volcano, the upper-middle slopes support sparse woody vegetation and tree ferns, and dense woody thickets are found within ravines and in lowland areas (Cruz et al. 2000; Mueller-Dombois and Fosberg 1998). Flatter areas have been planted with coconut groves. Native forests are confined to ravines on the southern and western slopes of Alamagan, and the forest cover on this island in general is low (Cruz et al. 2000). The southeastern lava slopes are devoid of vegetation (Fig. 12.1.2c), and landslides on this part of the island have disturbed vegetation. Compared to other islands in the CNMI, Alamagan has low abundance and density of native plant species (Cruz et al. 2000).

No information is available regarding the distribution of groundwater resources at Alamagan, although warm freshwater springs are present on the northern part of this island's west coast (Cruz et al. 2000). Surface water is thought to be absent except during rainy weather (Mueller-Dombois and Fosberg 1998).

Figure 12.1.2c. Vegetation cover on Alamagan, derived using the Normalized Difference Vegetation Index from a satellite image (grid cell size: 4 m; IKONOS Carterra Geo Data, 2001). Hatched lines indicate areas where data are not available because cloud cover obscures the satellite image.



12.1.3 Environmental Issues on Alamagan

Alamagan has relatively low abundance and density of native plant species. Several important species of birds reside on this island, including the Micronesian starling (*Aplonis opaca*), Micronesian honeyeater (*Myzomela rubrata*), and an estimated population of 30 of the Micronesian megapode (*Megapodius laperouse*), which is listed federally as endangered and locally as threatened or endangered (U.S. Fish and Wildlife Service; Berger et al. 2005). Alamagan has the only well-established population, outside of Saipan, of the nightingale reed warbler (*Acrocephalus luscini*), also listed federally as endangered and locally as threatened or endangered (U.S. Fish and Wildlife Service; Berger et al. 2005). The Mariana fruit bat (*Pteropus mariannus mariannus*), an endemic subspecies listed federally as threatened and locally as threatened or endangered (U.S. Fish and Wildlife Service; Berger et al. 2005), is present on this island, although the size of this population is unknown. Of the 3 northern islands (Alamagan, Asuncion, and Sarigan) that harbor substantial populations of the endemic Slevin's skink (*Emoia slevini*), Alamagan has the densest population (Cruz et al. 2000).

Native wildlife is threatened by the presence of feral cows, pigs, and goats, which are common on this island and can cause extensive damage to vegetation and destroy seedlings. Rats, although present, are lower in number than on other islands of the CNMI (Cruz et al. 2000).

As one of the few islands of the CNMI that has had a resident, if small, human population, Alamagan does not have the same isolation compared to the remote islands that have not been inhabited.

12.2 Survey Effort

Biological, physical, and chemical observations collected under the Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) have documented the conditions and processes influencing coral reef ecosystems around the island of Alamagan since 2003. The spatial extent and time frame of these survey efforts are discussed in this section. The disparate areas around this island often are exposed to different environmental conditions. To aid discussions of spatial patterns of ecological and oceanographic observations that appear throughout this chapter, 4 geographic regions around

Alamagan are delineated in Figure 12.2a; wave exposure and breaks in survey locations were considered when defining these geographic regions. This figure also displays the locations of the Rapid Ecological Assessment (REA) surveys, towed-diver surveys, and towed optical assessment device (TOAD) surveys conducted around this island. Potential reef habitat is represented by a 100-fm contour shown in white on this map.

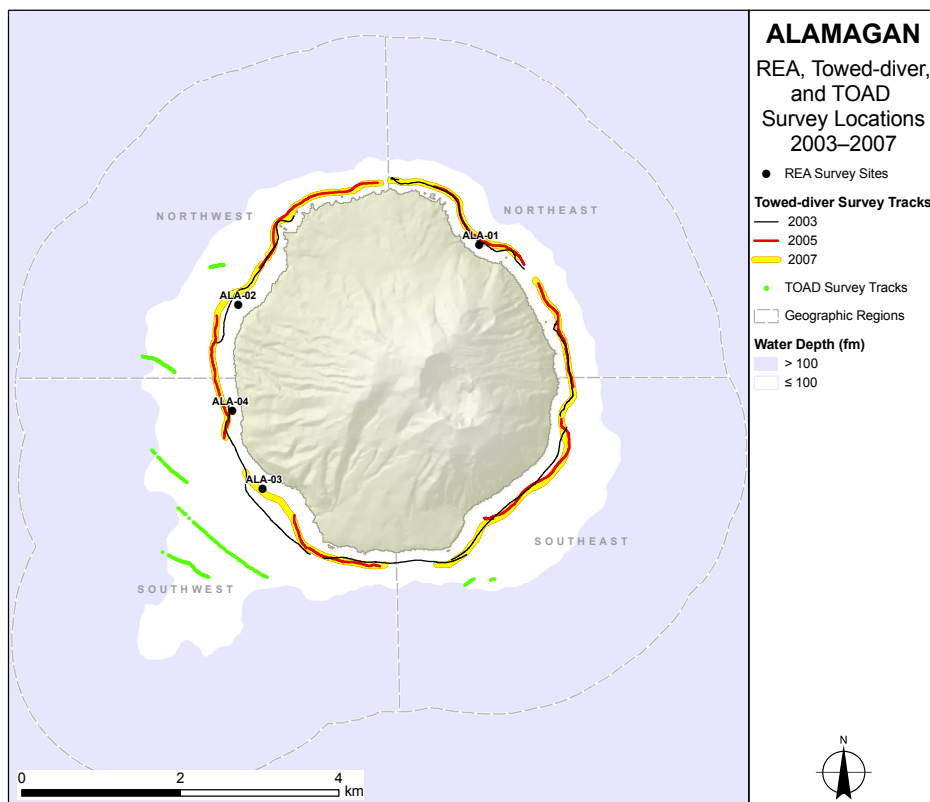


Figure 12.2a. Locations of REA, towed-diver, and TOAD benthic surveys conducted around Alamagan during MARAMP 2003, 2005, and 2007. To aid discussion of spatial patterns, this map delineates 4 geographic regions: north-east, southeast, southwest, and northwest.

Benthic habitat mapping data were collected around Alamagan using a combination of acoustic and optical survey methods. MARAMP benthic habitat mapping surveys conducted around this island with multibeam sonar covered a total area of 2228 km² in 2007. Optical validation and habitat characterization were completed using towed-diver and TOAD surveys that documented live-hard-coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in Section 12.3: “Benthic Habitat Mapping and Characterization.”

Information on the condition, abundance, diversity, and distribution of biological communities around Alamagan was collected using REA, towed-diver, and TOAD surveys. The results of these surveys are reported in Sections 12.5–12.8: “Corals and Coral Disease,” “Algae and Algal Disease,” “Benthic Macroinvertebrates,” and “Reef Fishes.” The numbers of surveys conducted during MARAMP 2003, 2005, and 2007 are presented in Table 12.2a, along with their mean depths and total areas and length.

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Alamagan were collected using (1) subsurface temperature recorders (STRs) designed for long-term observations of high-frequency variability of temperature, (2) closely spaced conductivity, temperature, and depth (CTD) profiles of the vertical structure of water properties, and (3) discrete water samples for nutrient and chlorophyll-*a* analyses. CTD casts were conducted during MARAMP 2003, 2005, and 2007, and water samples were collected during MARAMP 2007 (see Chapter 2: “Methods and Operational Background,” Section 2.3: “Oceanography and Water Quality”). A summary of deployed instruments and collection activities is provided in Table 12.2b. Results are discussed in Section: 12.4: “Oceanography and Water Quality.”

Table 12.2a. Numbers, mean depths (m), total areas (ha), and total length (km) of REA, towed-diver, and TOAD surveys conducted around Alamagan during MARAMP 2003, 2005, and 2007. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

Survey Type	Survey Detail	Year		
REA		2003	2005	2007
Fish	Number of Surveys	3	3	3
	Mean Depth (m)	12.3 (SD 2.1)	12.3 (SD 2.1)	12.3 (SD 2.1)
Benthic	Number of Surveys	3	3	3
	Mean Depth (m)	12.3 (SD 2.1)	12.3 (SD 2.1)	12.3 (SD 2.1)
Towed Diver		2003	2005	2007
	Number of Surveys	6	6	6
	Total Survey Area (ha)	12.1	10.1	13.2
	Mean Depth (m)	14.2 (SD 1.5)	15.9 (SD 1)	16.3 (SD 1.3)
TOAD		2003		
	Number of Surveys	6		
	Total Length (km)	3.59		

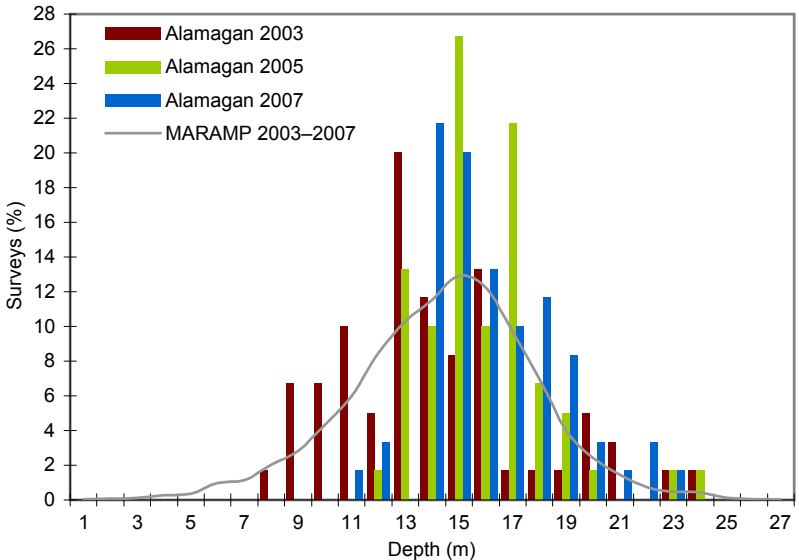
Table 12.2b. Numbers of STRs deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Alamagan during MARAMP 2003, 2005, and 2007. Shallow-water CTD casts and water samples were conducted from the surface to a 30-m depth, and deepwater casts were conducted to a 500-m depth. Deepwater CTD cast information is presented in Chapter 3: “Archipelagic Comparisons.”

Observation Type	Year						
Instruments	2003	2005		2007		2009	Lost
	Deployed	Retrieved	Deployed	Retrieved	Deployed	Retrieved	
STR	1	—	1	1	2	2	1
CTD Casts	2003	2005		2007			Total
Shallow-water Casts	14	15		16			45
Deepwater Casts	—	3		1			4
Water Samples		2005		2007			Total
		—		4			4

Towed-diver Surveys: Depths

Figures 12.2b and c illustrate the locations and depths of towed-diver-survey tracks around Alamagan and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

Figure 12.2b. Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted around Alamagan during MARAMP 2003, 2005, and 2007. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.



During MARAMP 2003, 6 towed-diver surveys were conducted along the forereef slopes around most of Alamagan (Figs. 12.2b and c, top panel). The mean depth of all survey segments was 14.2 m (SD 1.5), and the mean depths of individual surveys ranged from 12.9 m (SD 3.2) to 17 m (SD 6.1).

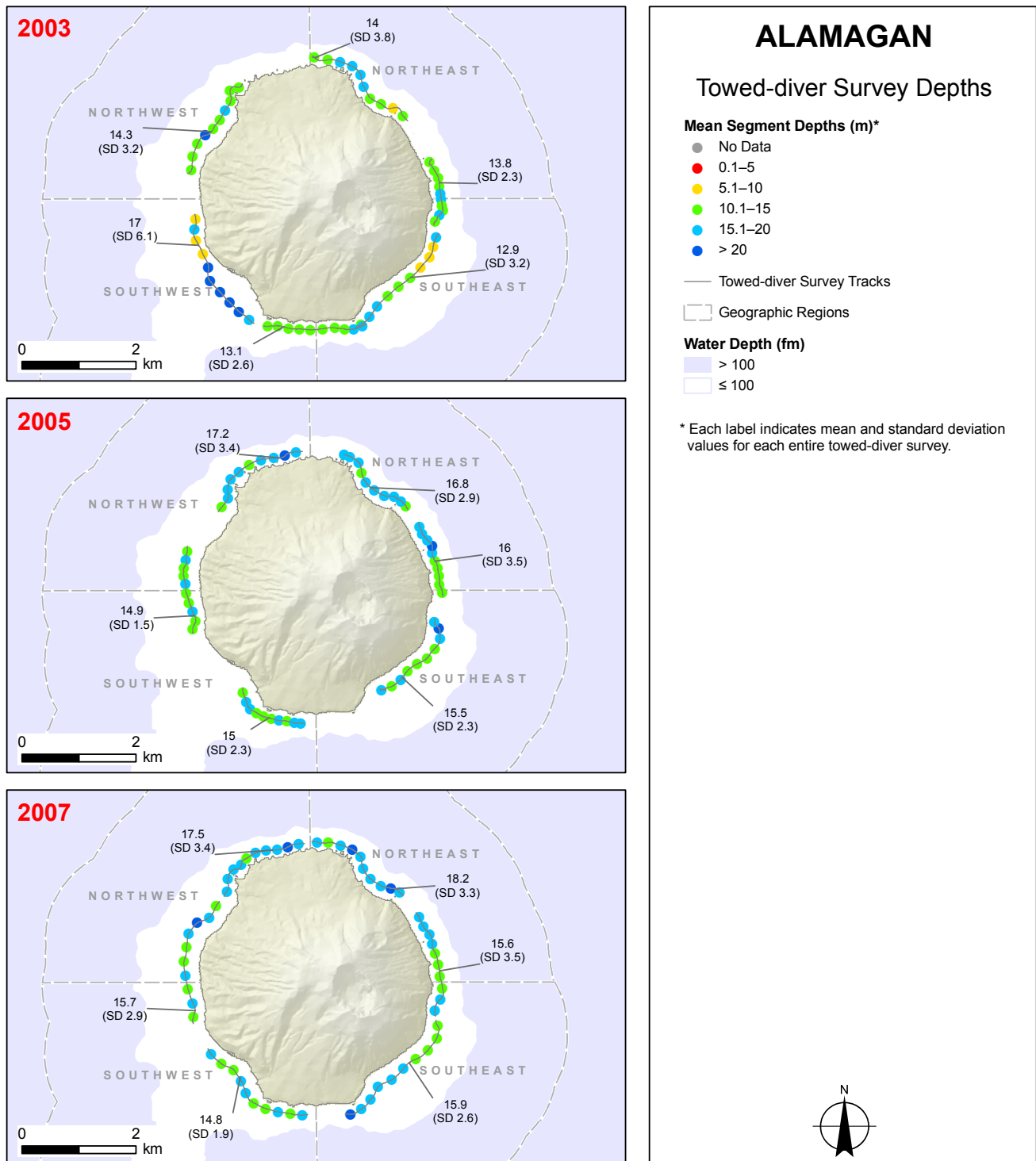


Figure 12.2c. Depths and tracks of towed-diver surveys conducted around Alamagan during MARAMP 2003, 2005, and 2007. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

During MARAMP 2005, 6 towed-diver surveys were conducted along the foreereef slopes around most of Alamagan (Figs. 12.2b and c, middle panel). The mean depth of all survey segments was 15.9 m (SD 1), and the mean depths of individual surveys ranged from 14.9 m (SD 1.5) to 17.2 m (SD 3.4).

During MARAMP 2007, 6 towed-diver surveys were conducted along most of the foreereef slopes of Alamagan (Figs. 12.2b and c, bottom panel). The mean depth of all survey segments was 16.3 m (SD 1.3), and the mean depths of individual surveys ranged from 14.8 m (SD 1.9) to 18.2 m (SD 3.3).

12.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization surveys of around the island of Alamagan were conducted during MARAMP 2003, 2005, and 2007 using acoustic multibeam sonar, underwater video and still imagery, and towed-diver observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products over the depth range of ~15–2300 m. Optical validation and benthic characterization, via diver observations and both video and still underwater imagery, were performed using towed-diver surveys and TOAD deployments conducted depths of 4–282 m.

12.3.1 Acoustic Mapping

Multibeam acoustic bathymetry and backscatter imagery (Fig. 12.3.1a) collected by the Coral Reef Ecosystem Division (CRED) around the islands of Alamagan, Sarigan, Anatahan, Guguan, and Zealandia Bank during MARAMP 2007 encompassed a total area of 2228 km². Multibeam data were obtained to depths of 1000–1700 m west of Alamagan, but additional data to 2300 m was obtained east of Alamagan, during transits to and from this island.

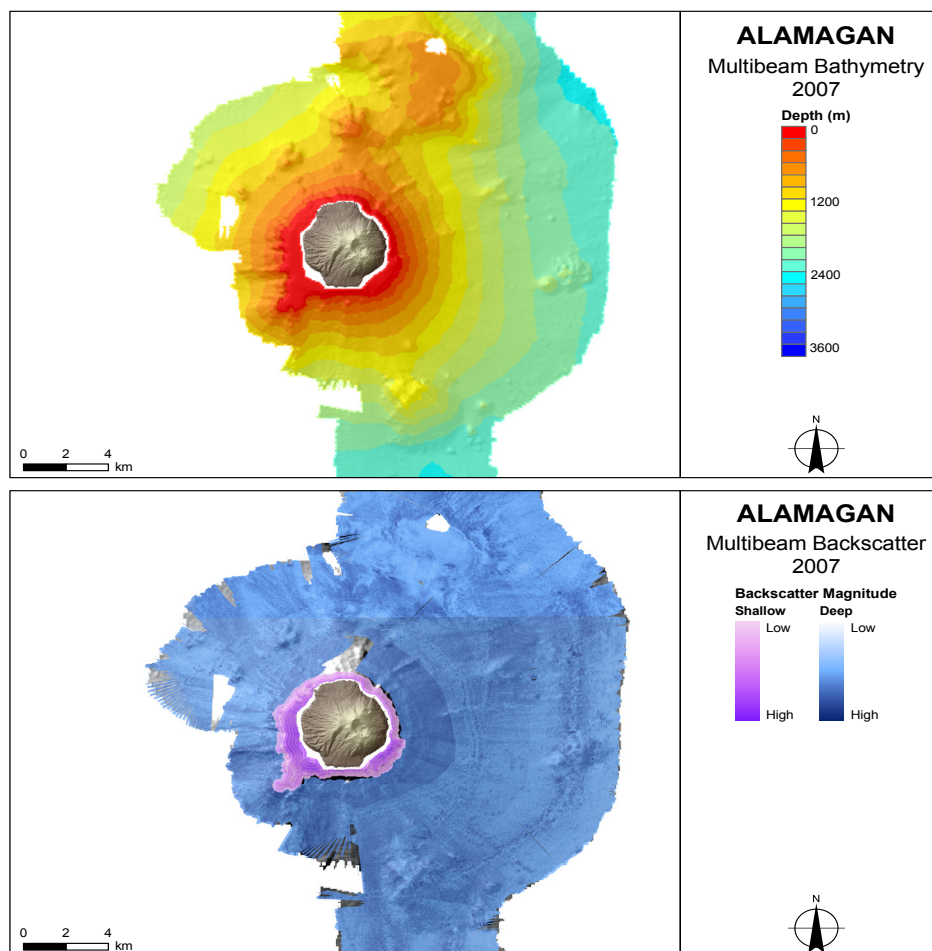


Figure 12.3.1a. Gridded (*top*) multibeam bathymetry (grid cell size: 60 m) and (*bottom*) backscatter (grid cell size: 5 m) collected around Alamagan during MARAMP 2007 at depths of 15–2300 m. Shallow-backscatter data (shown in purple) were collected using a 240-kHz Reson SeaBat 8101 ER sonar, and deep-backscatter data (shown in blue) were collected using a 30-kHz Kongsberg EM 300 sonar. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom or coral substrates.

Multibeam bathymetry acquired around Alamagan reveals part of the flanks of the Alamagan volcano (Fig. 12.3.1a, top panel). The acquired data do not entirely cover the flanks, but data obtained east of Alamagan suggest that the seabed descends to ~2000 m within 6.5 km from the coast and continues to descend, albeit less steeply, beyond this point. These low-resolution data also reveal a small shelf extending from the southwest of this island. North of Alamagan, a small pinnacle is visible, with a larger bank further northeast. Smaller peaks are shown elsewhere around this island.

As described in Chapter 2: “Methods and Operational Background,” Section 2.2: “Benthic Habitat Mapping and Characterization,” multibeam backscatter intensity can provide information about the roughness and hardness of the seafloor. Backscatter data acquired around Alamagan show some variation in intensity that may relate to variation in the acoustic nature of the seabed, although noticeable artifacts also are observed. East of this island, the shallowest swath of backscatter data (Fig. 12.3.1a, bottom panel) is noticeably darker than the deeper swaths, which may be a result of changes in the settings during data acquisition. Low-intensity backscatter—observed on the bank northeast of Alamagan, in contrast to edges of the bank, where backscatter intensity is higher—may indicate the presence of soft sediments on the bank top. The pinnacle between the bank and Alamagan and other pinnacles on the eastern flanks are represented by high-intensity backscatter, suggesting that hard substrates may be at or close to the seabed surface here. Around southwestern Alamagan, high-intensity backscatter also is shown on the shallow shelf.

High-Resolution Multibeam Bathymetry and Derivatives

High-resolution multibeam data collected in nearshore (depths of 0–800 m) waters around Alamagan were combined into a grid at 10-m resolution for the identification of fine-scaled features (Fig. 12.3.1b). These high-resolution data were used to derive maps of slope (Fig. 12.3.1c), rugosity (Fig. 12.3.1d), and bathymetric position index (BPI) zones (Fig. 12.3.1e). Together, these maps provide layers of information to characterize the benthic habitats around Alamagan.

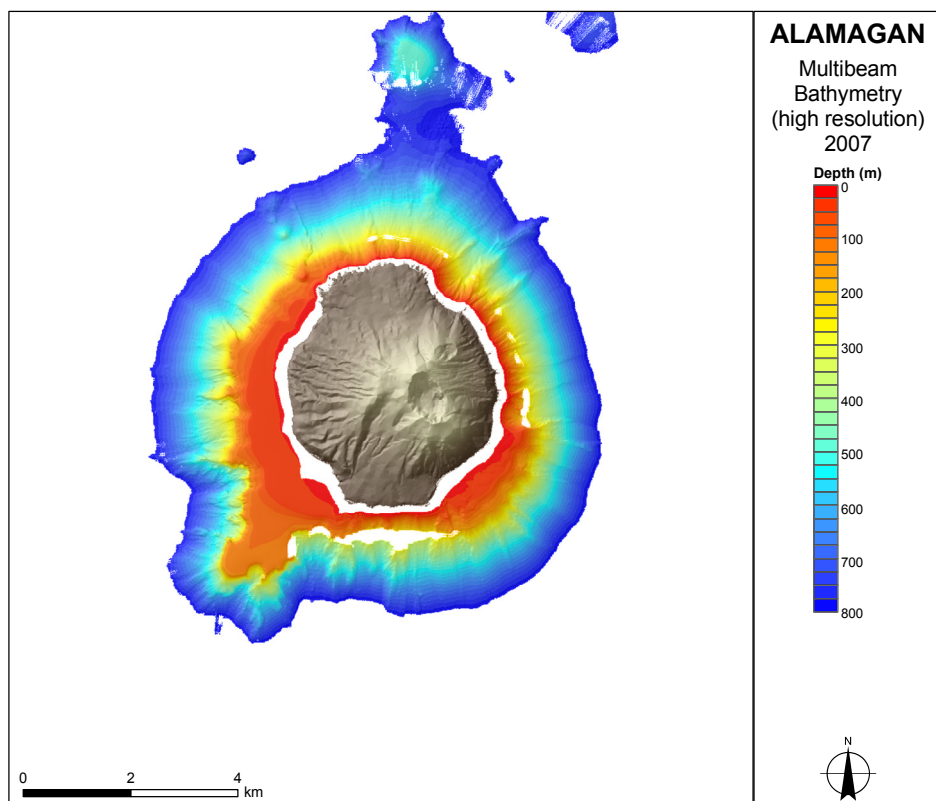
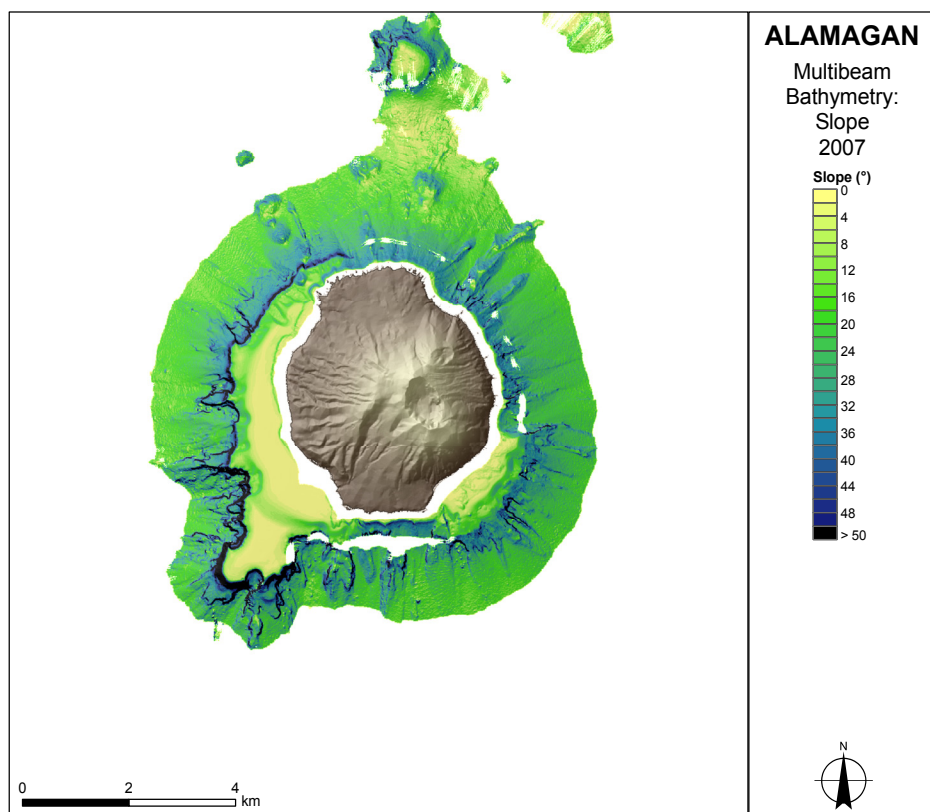


Figure 12.3.1b. High-resolution multibeam bathymetry collected around Alamagan during MARAMP 2007. This 10-m bathymetry grid, clipped at 800 m, is used as the basis for slope, rugosity, and BPI derivatives.

Around northern and northeastern Alamagan, the slope map and BPI analysis highlight many ridges that incise moderately steep (20° – 25°) flanks. All of the ridges in this area are narrow and steep-sided, with high rugosity values recorded on the sides.

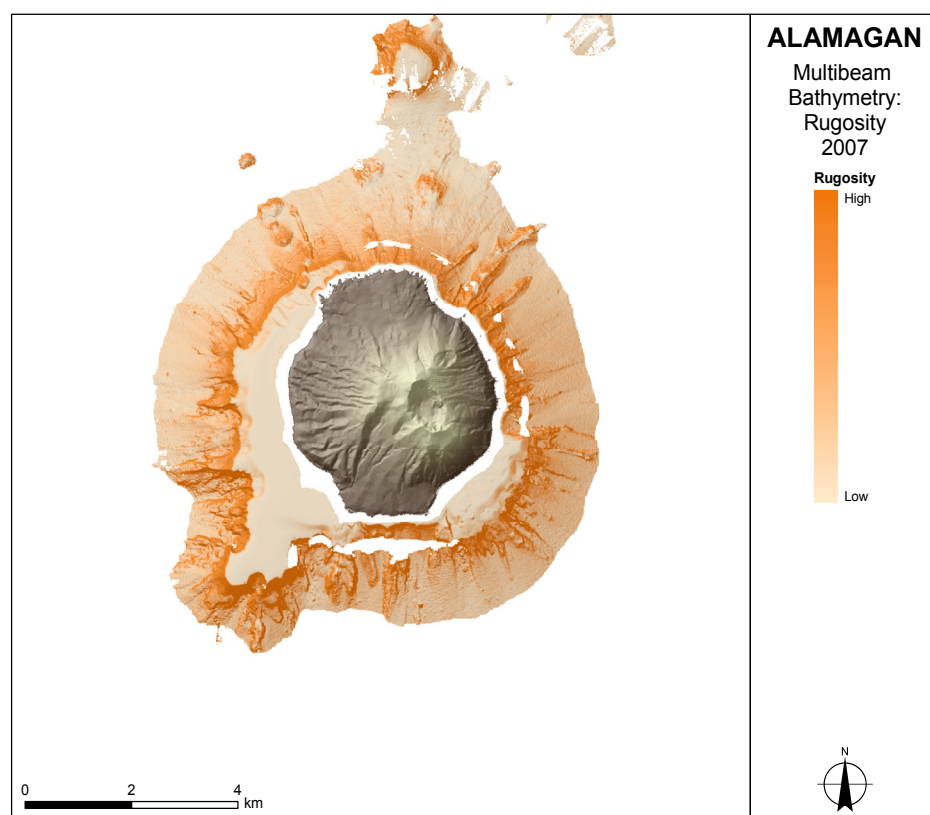
Southeast of Alamagan, the most significant topographic feature depicted on the map of BPI zones is a narrow shelf, the surface of which is shown in the slope and rugosity maps to have a somewhat complex texture, which suggests coral habitat

Figure 12.3.1c. Slope ($^{\circ}$) of 10-m bathymetric grid around Alamagan. Derived from data collected in 2007, this map reflects the maximum rate of change in elevation between neighboring cells with the steepest slopes shown in the darkest shades of blue and the flattest areas in yellow shades.



or may result from onshore landslide deposits. Below the shelf, the smooth moderately sloping (15° – 20°) seabed gives way to more steeply sloping flanks incised with ridges, similar in character to the flanks northeast of this island.

Figure 12.3.1d. Rugosity of 10-m bathymetric grid around Alamagan. Derived from data collected in 2007, these rugosity values are a measure of the ratio of surface area to planimetric area within a given cell's neighborhood and indicate topographic roughness.



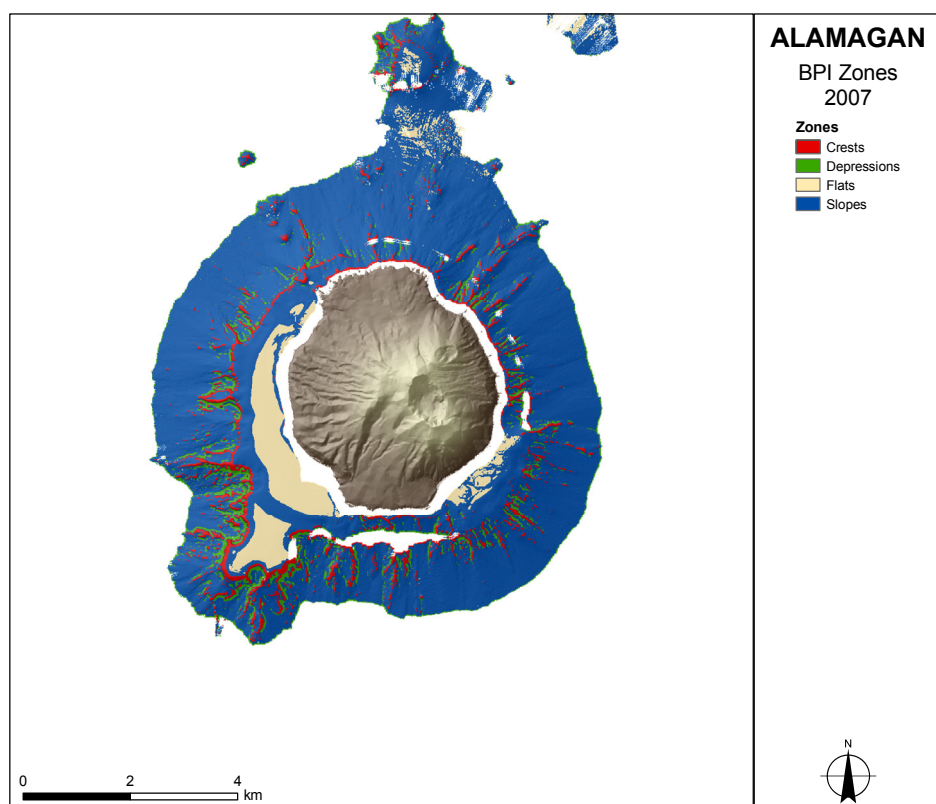


Figure 12.3.1e. BPI zones of 10-m bathymetric grid around Alamagan derived from data collected in 2007. BPI is a second-order derivative of bathymetry that evaluates elevation differences between a focal point and the mean elevation of the surrounding cells within a user-defined circle. Four BPI Zones—crests, depressions, flats, and slopes—have been used in this analysis.

A more extensive shelf area is present around western Alamagan at depths of 25–40 m. In the southwest, a second, deeper shelf is present at depths of 80–120 m and extends for a further 1.5 km. Both shelves are characterized by very smooth, flat surfaces and create extensive flat zones in a seabed otherwise dominated by slopes. The shelves are edged by very steep slopes ($> 50^\circ$); in deeper water, the flanks are more moderately steep and characterized by medium-high rugosity values.

Directly north and south of Alamagan, no such shelf areas are present. South of Alamagan the onshore lava platform creates an extension to the coast below which the seabed slopes steeply. North of this island, the coastline has been similarly extended by a lava flow. Offshore, north of Alamagan, a topographic high is revealed by the high-resolution bathymetry, arising to a depth of ~ 480 m. Small flat areas are defined by the BPI analysis on top of this peak, surrounded by steep, high-rugosity slopes with some ridge features.

High-Resolution Multibeam Backscatter and Derivatives

The high-resolution backscatter data acquired around Alamagan were affected by some artifacts, such as higher backscatter values recorded within the shallower part of the outer swath versus the deeper part. Backscatter data can be affected by steep slopes, sonar settings, sea state during data acquisition, or other factors discussed in more detail in Chapter 2: “Methods and Operational Background,” Section 2.2.2 “Acoustic Mapping.” Track parallel artifacts visible on the shelf southwest of Alamagan were exaggerated in the hard–soft analysis. The resulting hard–soft substrate map was therefore clipped to exclude these data.

Despite data quality issues, a number of clear patterns are shown in the backscatter intensity recorded around this island, particularly where more complete coverage was achieved (Fig. 12.3.1f). Around north and northeast Alamagan, some of the more prominent ridge features were associated with high-intensity backscatter values indicative of hard substrates. The shallow shelf areas around the south and west of this island were all characterized by high-intensity backscatter, categorized through the hard–soft analysis as being dominated by hard substrates. Along the southern edge of the southeastern shelf, a band of low-intensity backscatter is associated with a channel shown in the bathymetry. This channel is highlighted in the hard–soft substrate map as being an area of soft substrate on an otherwise hard-substrate shelf (Fig. 12.3.1g). The deeper shelf southwest of Alamagan appeared to have lower backscatter intensity, although it may have been affected to some extent by the deeper water being surveyed, and artifacts in these data make interpretation difficult. Around northwestern Alamagan, low backscatter values were recorded in a number of channels visible in the multibeam bathymetry, and the hard–soft analysis suggests that the seabed here is likely to be characterized by soft sediments.

Figure 12.3.1f. Gridded, high-resolution, multibeam backscatter data (grid cell size: 1 m) collected around Alamagan during MARAMP 2007. Light shades represent low-intensity backscatter and may indicate acoustically absorbent substrates. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom and coral substrates. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.

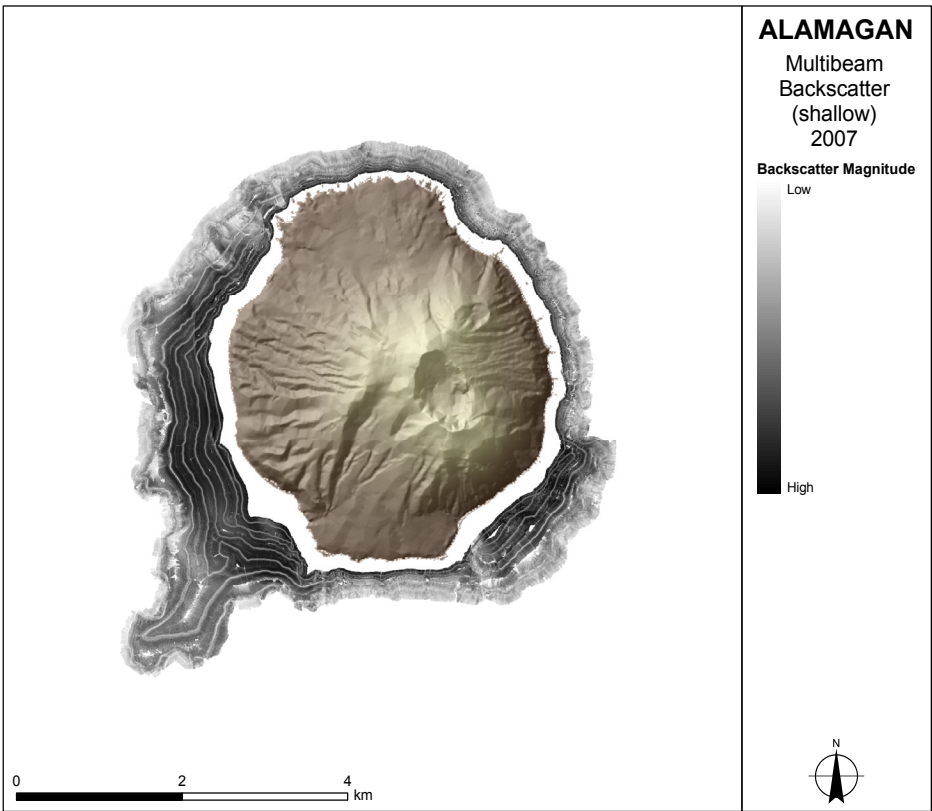
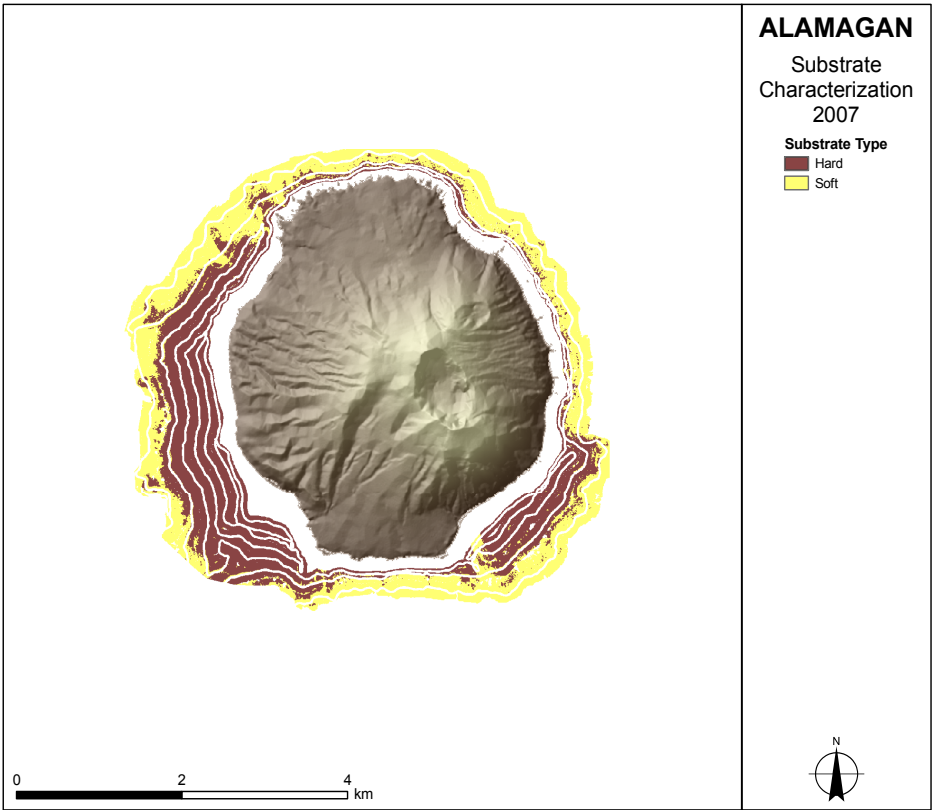


Figure 12.3.1g. Hard and soft substrates (grid cell size: 5 m) based upon an unsupervised classification of multibeam bathymetry and backscatter data acquired around Alamagan in 2007. Data cannot be collected directly under the ship, hence the white lines showing the ship's path.



12.3.2 Optical Validation

During MARAMP 2003, 6 TOAD optical-validation surveys, covering a distance of 3.6 km, were conducted around Alamagan at depths of 45–280 m (Fig. 12.3.2a). Subsequent analyses of video acquired from these surveys provided estimates of the percentages of sand cover and live coral cover.

Covering a distance of 35 km in depths of 4–28 m, 18 towed-diver optical-validation surveys were conducted around Alamagan during MARAMP 2003, 2005, and 2007. At 5-min intervals within each survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high.

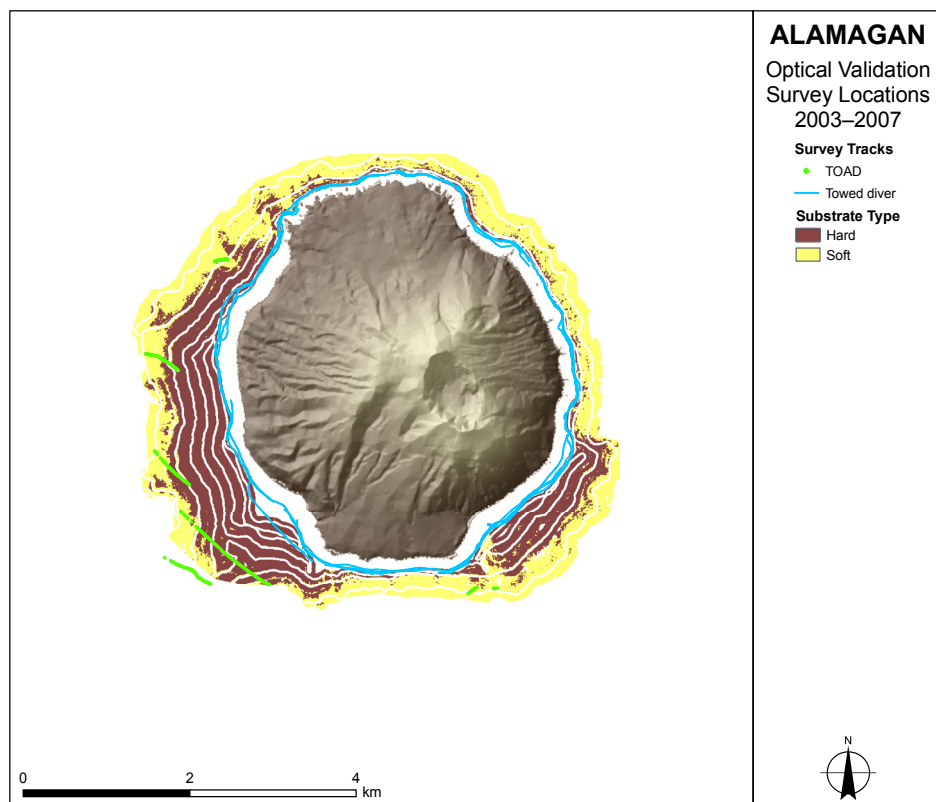


Figure 12.3.2a. Towed-diver tracks from surveys conducted around Alamagan during MARAMP 2003, 2005, and 2007 and TOAD camera-sled tracks for MARAMP 2003. Survey tracks are displayed over the multibeam hard–soft substrate map. Data cannot be collected directly under the ship, hence the white lines showing the ship’s path.

12.3.3 Habitat Characterization

Sand cover, habitat complexity, and live coral cover around Alamagan are discussed in this section. These descriptions are organized by the 4 geographic regions around Alamagan.

Around northeastern Alamagan, very low sand cover was observed during towed-diver surveys with cover predominantly < 10% (Fig 12.3.3a, top panel). Habitat complexity observed during towed-diver surveys ranged from medium to high (Fig 12.3.3a, middle panel). This high level of complexity reflects the ridges visible on the bathymetry that provide high relief. Towed-diver surveys characterized this habitat as containing steep reef slopes, boulders with corals, and perpendicular ridges. This hard substrate area coincides with the onshore geology of northern and eastern Alamagan, which is dominated by lava flows (Moore and Trusdell 1993). Live coral cover was estimated at 10.1%–40% (Fig 12.3.3a, bottom panel).

Across the shallow shelf southeast of Alamagan, towed-diver surveys found habitats of boulders on sand, and high-relief spur-and-groove formations. Habitat complexity within this region was recorded as lower than the level observed north-east of Alamagan, ranging from medium-low to medium-high, because no ridges providing high relief were present. Towed-diver surveys recorded higher sand cover than the levels seen in the northeast region (generally 10.1%–40%), including one patch of 85% cover on the southwestern edge of the shelf. This area coincided with a band of low-intensity backscatter and a channel on the edge of the shelf. Observed live coral cover was lower here than further north, with cover predominantly of 5.1%–20%.

An area of low-complexity habitat observed on the shelf southwest of Alamagan was characterized by sand cover of 50.1%–100% and low (< 10%) live coral cover. Parallel surveys conducted closer inshore recorded slightly higher habitat complexity and lower cover of sand, suggesting that sand cover over the shelf area could be spatially variable. The presence of sand in this area coincides with onshore beach deposits, otherwise rare around Alamagan (Moore and Trusdell 1993). Multibeam backscatter data collected over the shelf area revealed predominantly high-intensity backscatter, although some areas of slightly lower intensity were mapped. These data normally would suggest the presence of hard substrates at the seabed surface. This apparent contradiction between the acoustic data and diver observations may be a result of divers observing a thin veneer of sand overlying harder substrates.

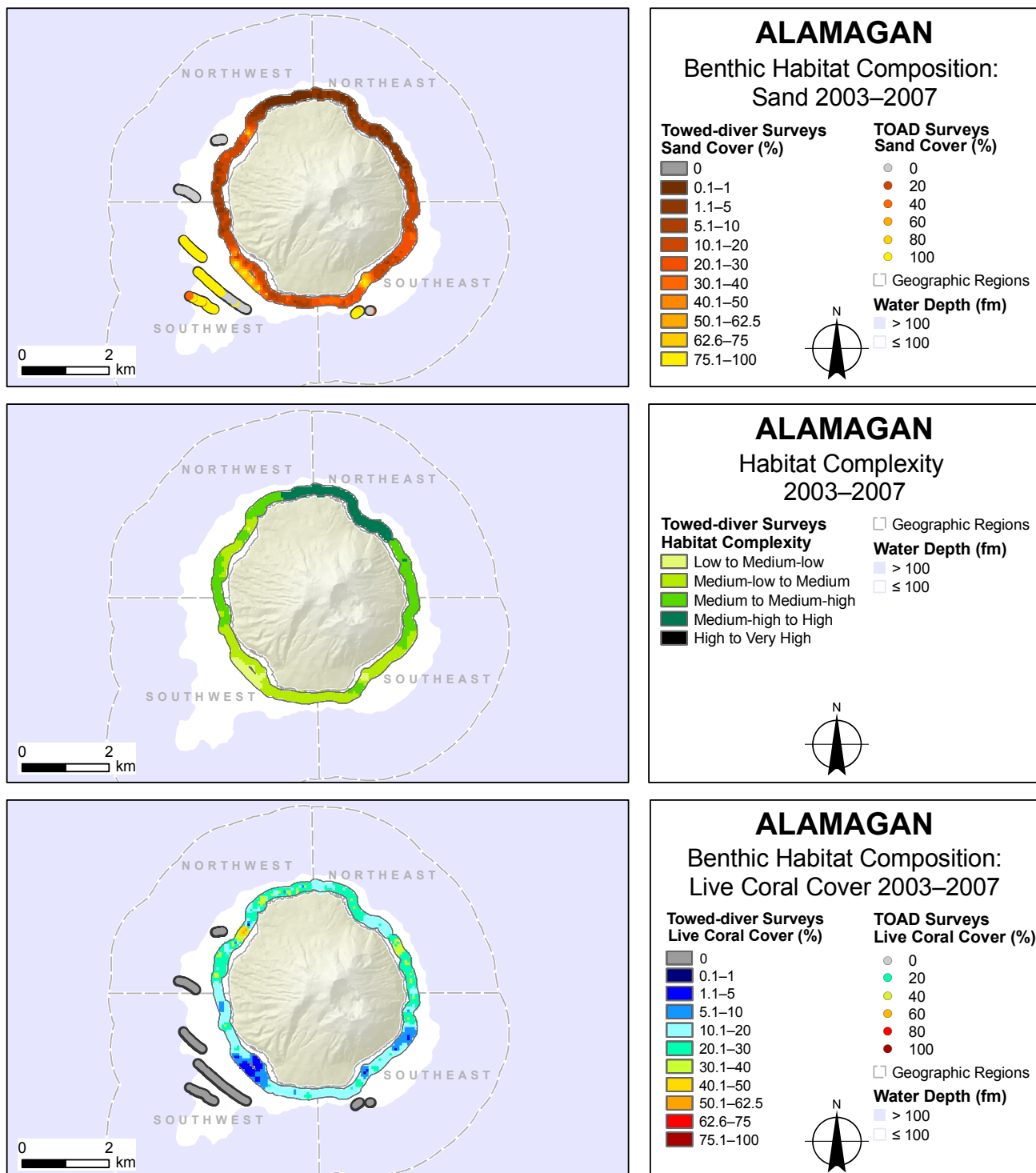


Figure 12.3.3a. Observations of (top) sand cover (%), (middle) benthic habitat complexity, and (bottom) live-hard-coral cover (%) from towed-diver surveys conducted and analyses of TOAD video collected around Alamagan during MARAMP 2003, 2005, and 2007.

Within the rest of the southwest region, habitat complexity observed during towed-diver surveys was medium-low to medium, with moderately low cover of sand ($< 30\%$) and live hard corals (10.1% – 20%). These data suggest that the seabed here is predominantly composed of hard substrates but supports low levels of live corals. Towed-diver surveys described habitats as consisting of rolling reef, moderate reef slope and boulder fields. Onshore geology in this area is dominated by pyroclastic flow deposits, which include weakly consolidated pumice and boulders (Moore and Trusdell 1993).

Analyses of video obtained from TOAD surveys conducted on the deeper of the two shelf areas southwest of Alamagan revealed predominantly sandy habitats, with benthic substrate observed in video frames from 2 entire surveys and half of the third classified as 100% sand cover. No live corals were observed during video analyses. This absence of coral cover is in apparent contradiction to the hard–soft analysis, which depicts this shelf area as one composed of hard substrates. This difference may result from a hard shelf area being overlain by a thin veneer of soft sediment, visible on the TOAD video, but of insufficient thickness to influence the backscatter return.

In the northwest region, towed-diver surveys conducted along the shelf revealed habitat complexity of medium-low to medium-high, with fairly low sand cover ($< 20\%$), although one small patch of high sand cover was observed, coinciding with an area of low-intensity backscatter. Live coral cover was patchy, varying between 1% and 75.1%–100%. Habitats were characterized as continuous reef with patches of boulder and rubble. Analyses of video footage from 2 TOAD surveys suggested no cover of sand or live corals. For both surveys, the substrate was classified as unconsolidated sediment devoid of live fauna.

12.4 Oceanography and Water Quality

12.4.1 Hydrographic Data

2003 Spatial Surveys

During MARAMP 2003, 14 shallow-water conductivity, temperature, and depth (CTD) casts were conducted in nearshore waters around the island of Alamagan on September 12. Temperature, salinity, and density values varied both spatially and vertically. Spatial comparisons of water properties at a depth of 10 m suggest moderate ranges in temperature (0.41°C), salinity (0.18 psu), and density (0.26 kg m^{-3}) values around Alamagan. Recorded temperatures were lower and, concurrently, salinity and density were higher in the northeast region (casts 5–8) than in other regions (Fig. 12.4.1a). Vertical comparisons of CTD profiles (Fig. 12.4.1b) also reveal moderate ranges in temperature (0.6°C), salinity (0.3 psu), and density (0.4 kg m^{-3}) values. As seen in spatial comparisons, temperature, salinity, and density values in the northeast region (casts 5–8) were markedly different compared to all other cast locations around Alamagan. These observed differences in temperature and salinity values in the northeast region likely result from upwelling of subsurface waters, although the physical oceanographic forcing mechanism behind this upwelling is unknown without further information.

2005 Spatial Surveys

During MARAMP 2005, 15 shallow-water CTD casts were conducted in nearshore waters around Alamagan on September 16. Temperature, salinity, density, and beam transmission values varied both spatially and vertically. Spatial comparisons of water properties at a depth of 10 m suggest little spatial heterogeneity with small ranges in temperature (0.07°C), salinity (0.04 psu), density (0.03 kg m^{-3}), and beam transmission ($< 1\%$) values (Fig. 12.4.1c). Vertical comparisons of CTD profiles (Fig. 12.4.1d) reveal similarly small ranges in temperature (0.2°C), salinity (0.1 psu), density (0.1 kg m^{-3}), and beam transmission ($< 1\%$) values around Alamagan. Recorded temperatures were slightly cooler in the southeast region (casts 12–14) than at other cast locations around this island.

ALAMAGAN

10-m CTD Data 2003

Water Depth (fm) 5 Cast Number

Geographic Regions

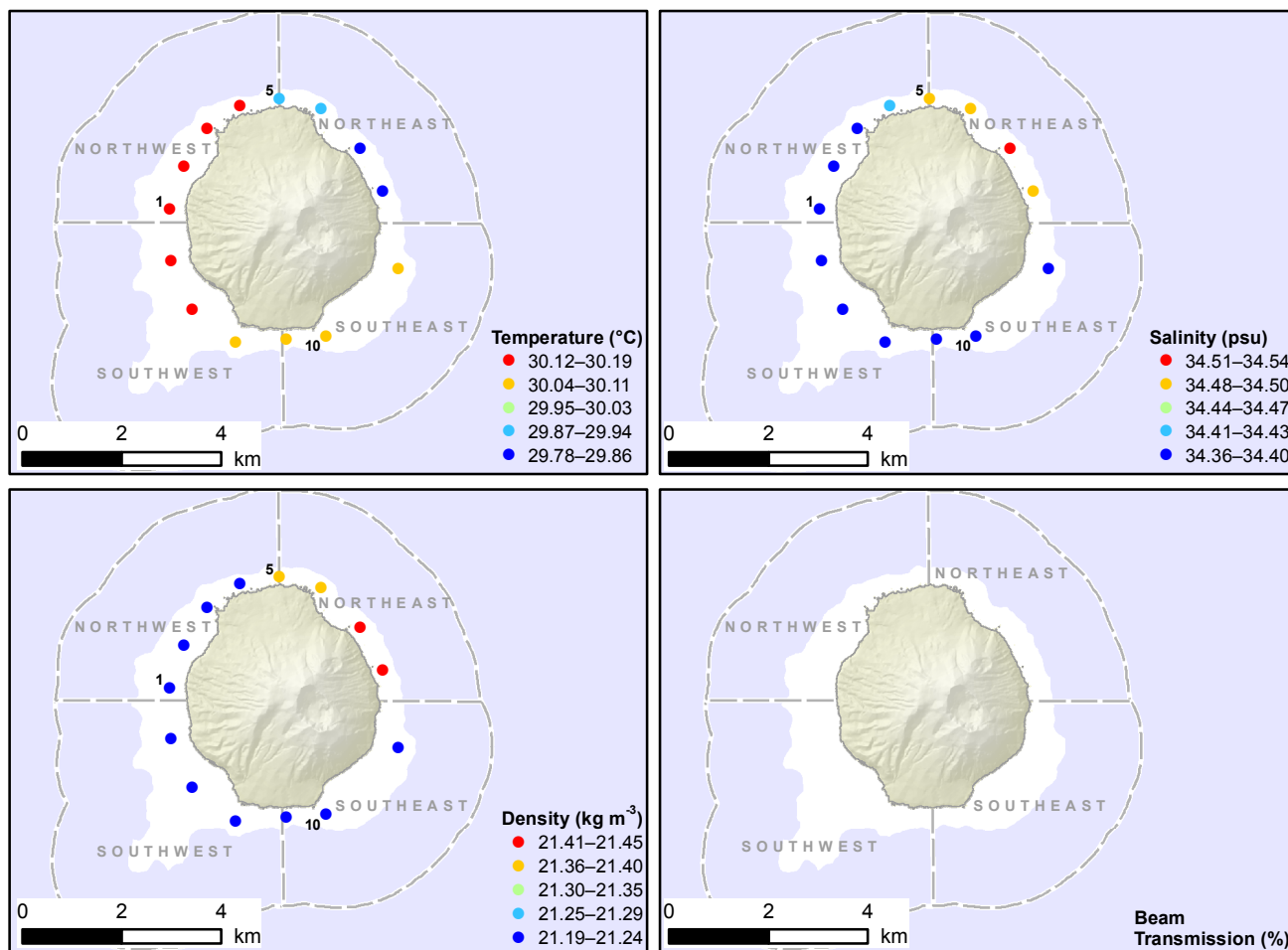
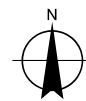
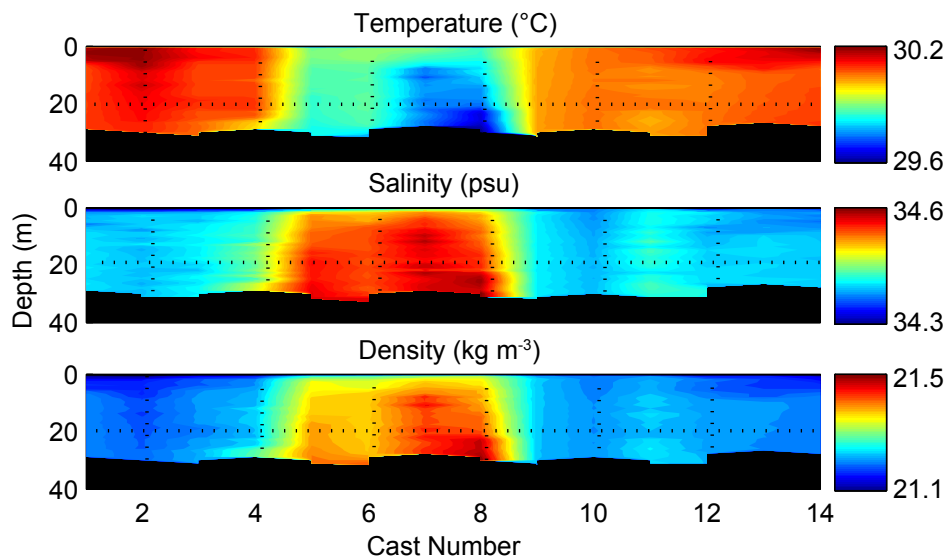


Figure 12.4.1a. Values of (top left) water temperature, (top right) salinity, and (bottom left) density at a 10-m depth from shallow-water CTD casts around Alamagan on September 12 during MARAMP 2003.

Figure 12.4.1b. Shallow-water CTD cast profiles to a 30-m depth around Alamagan on September 12 during MARAMP 2003, including temperature (°C), salinity (psu), and density (kg m⁻³). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–14 in a clockwise direction around Alamagan. For cast locations and numbers around this island in 2003, see Figure 12.4.1a.



ALAMAGAN

10-m CTD Data 2005

Water Depth (fm) 5 Cast Number

> 100
≤ 100

Geographic Regions

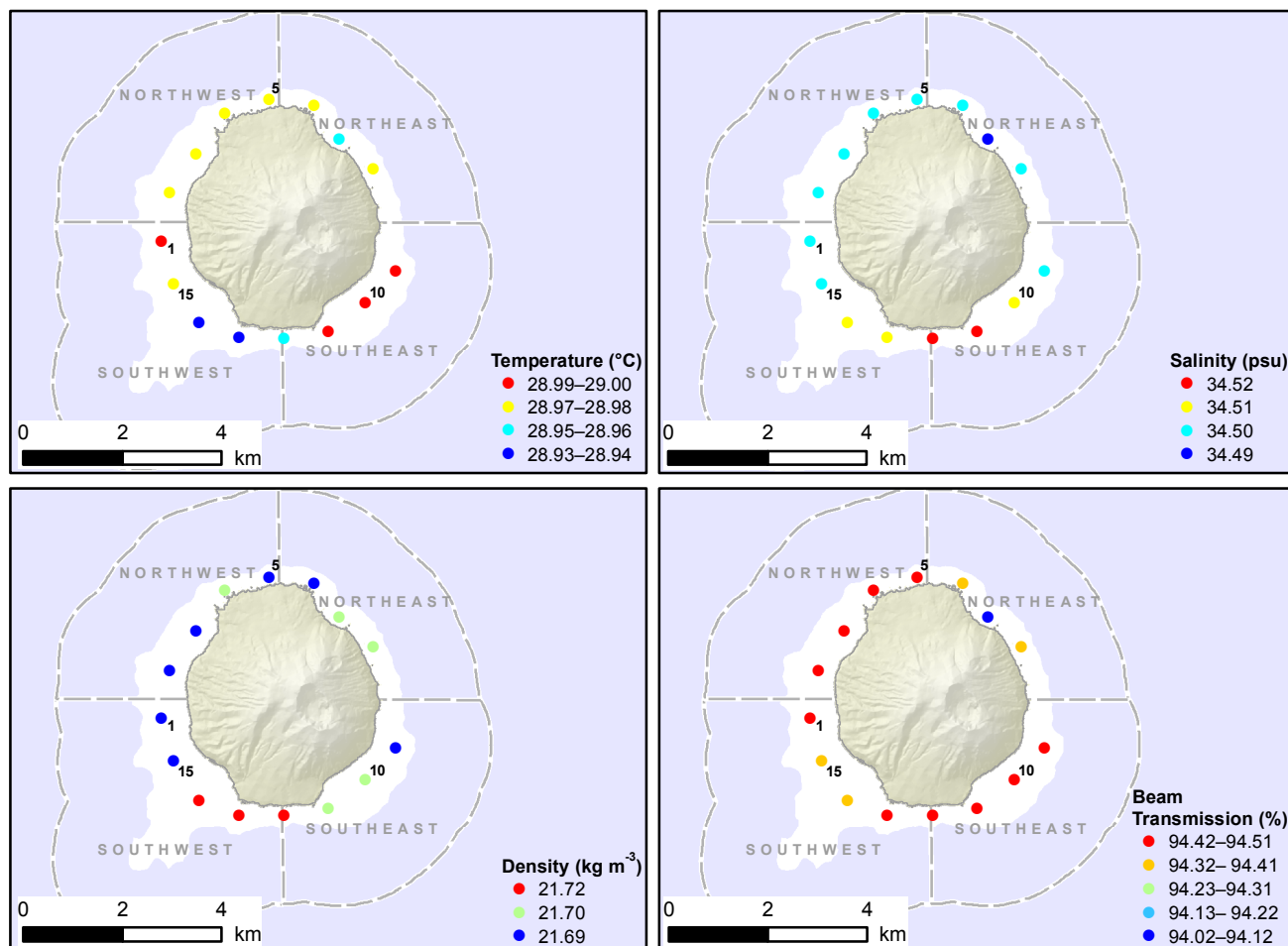


Figure 12.4.1c. Values of (top left) water temperature, (top right) salinity, (bottom left) density (bottom right) beam transmission at a 10-m depth from shallow-water CTD casts around Alamagan on September 16 during MARAMP 2005.

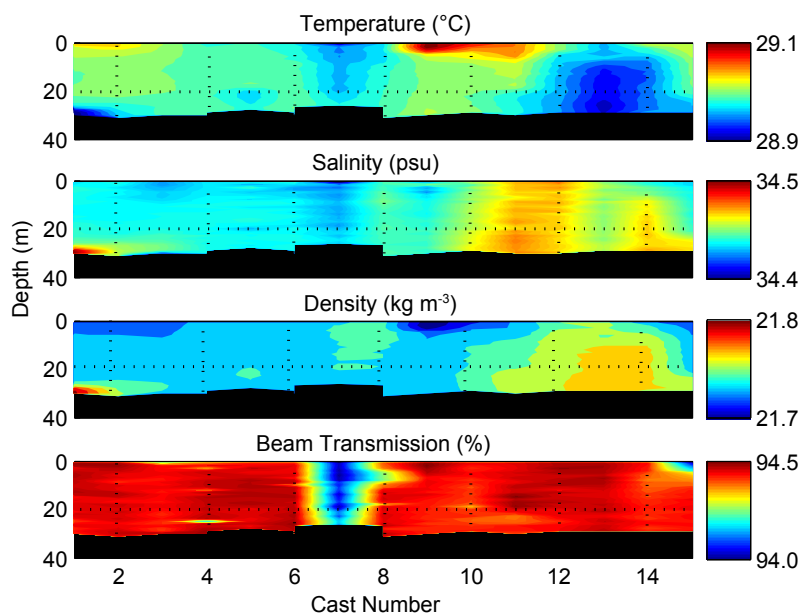


Figure 12.4.1d. Shallow-water CTD cast profiles to a 30-m depth around Alamagan on September 16 during MARAMP 2005, including temperature (°C), salinity (psu), density (kg m⁻³), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–15 in a clockwise direction around Alamagan. For cast locations and numbers around this island in 2005, see Figure 12.4.1c.

2007 Spatial Surveys

During MARAMP 2007, 16 shallow-water CTD casts were conducted in nearshore waters around Alamagan on May 28. Temperature, salinity, density, and beam transmission values varied both spatially and vertically. Spatial comparisons of water properties at a depth of 10 m suggest moderate variability in temperature (0.67°C) values and small ranges in salinity (0.05 psu), density (0.19 kg m⁻³), and beam transmission (< 1%) values. Two cool areas, relative to other cast locations around Alamagan, were recorded in the northeast (cast 7) and northwest (cast 5) regions. In general, waters were slightly cooler in the northwest and southwest regions than in the northeast and southeast regions (Fig. 12.4.1e). Vertical comparisons of CTD profiles (Fig. 12.4.1f) reveal an east–west gradient in stratification, with stratified conditions observed in the northeast and southeast regions (casts 6–12) and well-mixed waters found in the northwest and southwest regions (casts 1–5, 14–16). A broad range in water temperature (1.3°C) values, moderate ranges in salinity (0.2 psu) and density (0.5kg m⁻³) values, and a small range in beam transmission (< 1%) values were recorded.

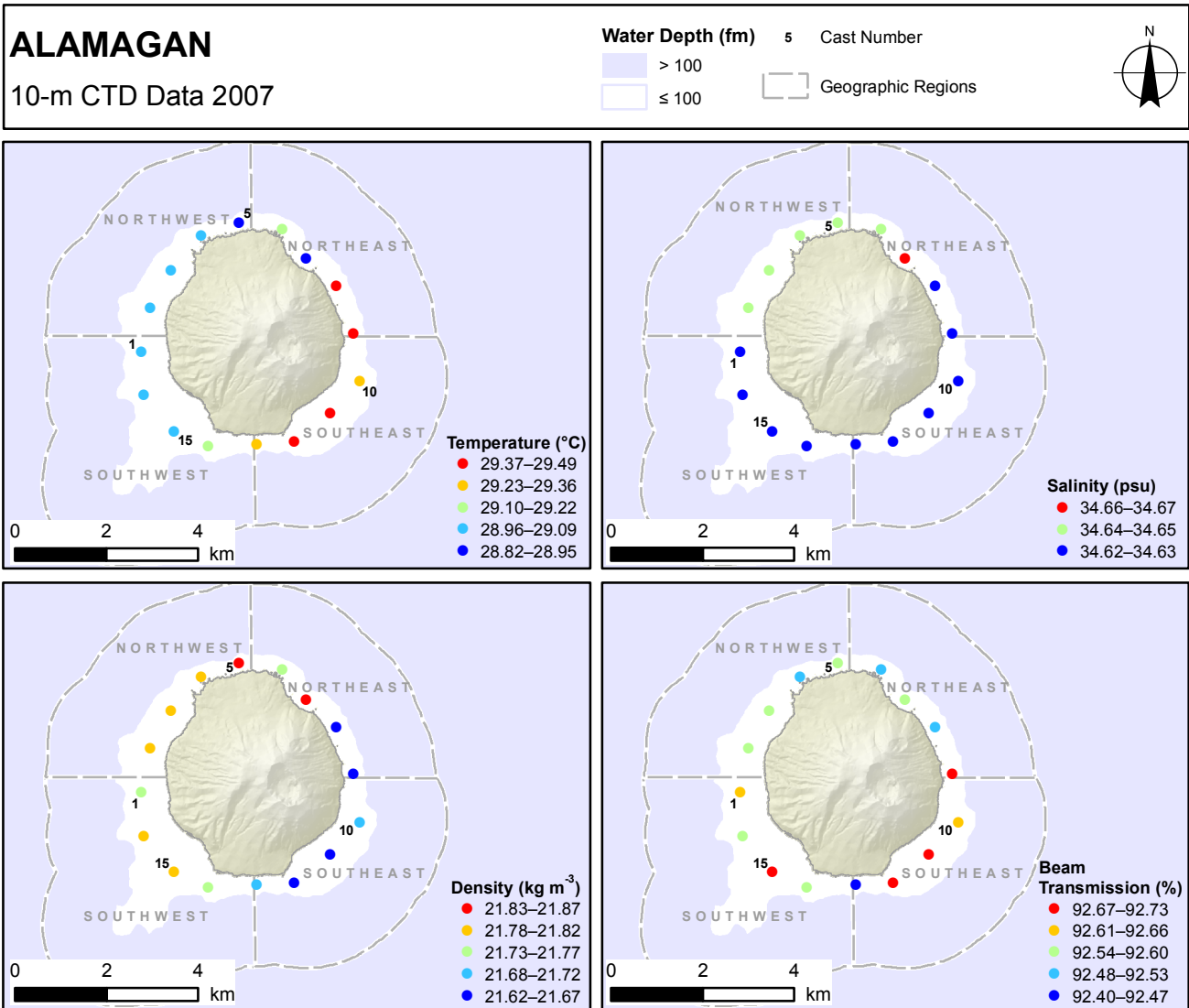


Figure 12.4.1e. Values of (top left) water temperature, (top right) salinity, (bottom left) density, and (bottom right) beam transmission at a 10-m depth from shallow-water CTD casts around Alamagan on May 28 during MARAMP 2007.

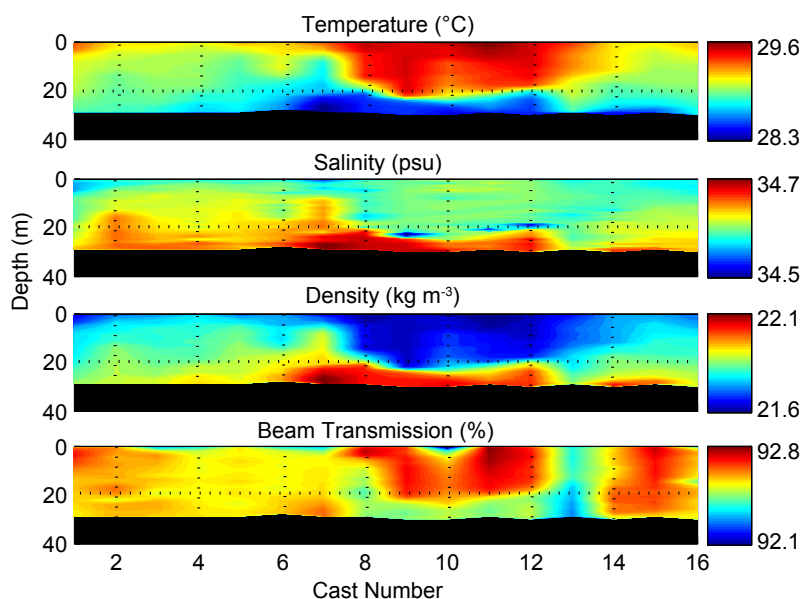


Figure 12.4.1f. Shallow-water CTD cast profiles to a 30-m depth around Alamagan on May 28 during MARAMP 2007, including temperature (°C), salinity (psu), density (kg m⁻³), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–16 in a clockwise direction around Alamagan. For cast locations and numbers around this island in 2007, see Figure 12.4.1e.

Water samples were collected in concert with shallow-water CTD casts at 4 select locations at Alamagan to assess water-quality conditions. The following ranges of measured parameters were recorded: chlorophyll-*a* (Chl-*a*), 0.058–0.074 µg L⁻¹; total nitrogen (TN), 0.003–0.055 µM; nitrate (NO₃⁻), 0.002–0.050 µM; nitrite (NO₂⁻), 0.001–0.006 µM; phosphate (PO₄³⁻), 0.035–0.040 µM; and silicate (Si[OH]₄), 1.13–1.29 µM. In general, water-quality parameters were low in 2007, typical of the Western Pacific Warm Pool's oligotrophic, oceanic surface layers. The highest Chl-*a* values were observed in the northeast and southwest regions, while the highest values of total nitrogen, nitrate, nitrite, and silicate were found in the northwest and southwest regions (Fig. 12.4.1g). Levels of phosphate and silicate were relatively homogenous in all 4 regions.

ALAMAGAN

10-m Nutrient Data 2007

Water Depth (fm)  Geographic Regions

> 100
≤ 100

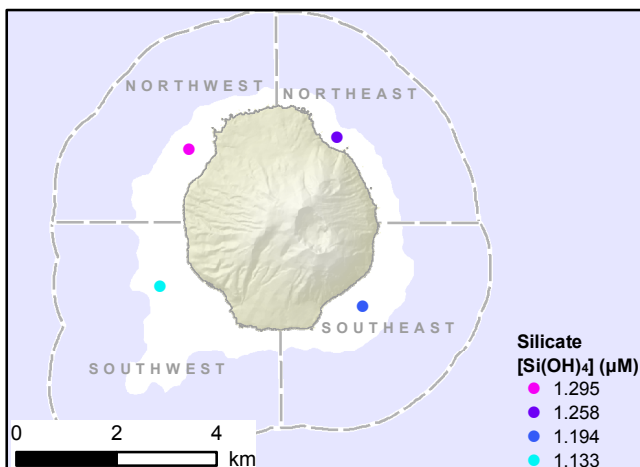
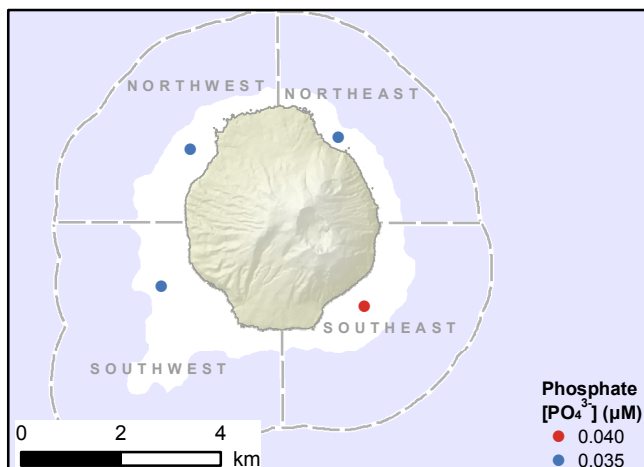
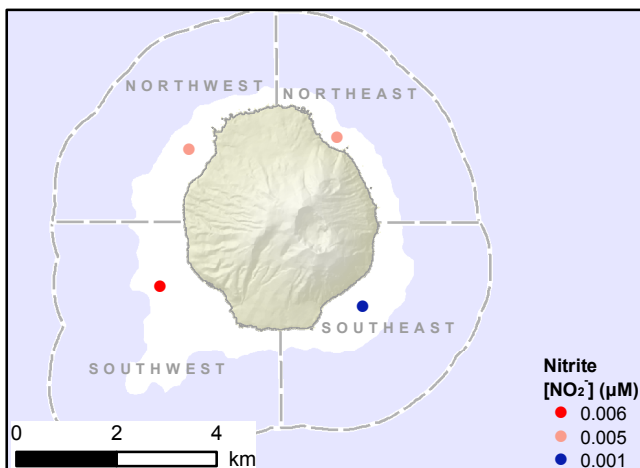
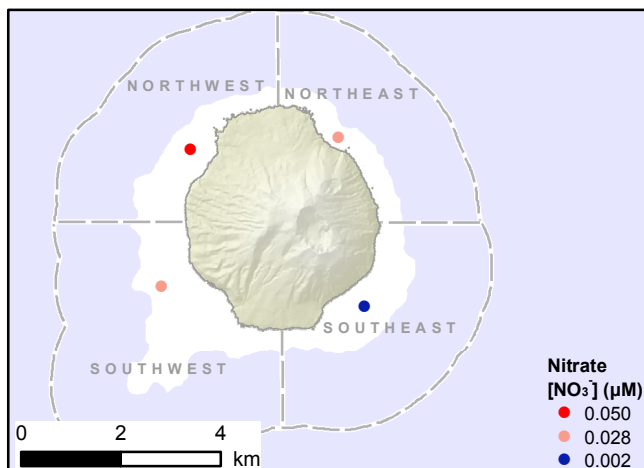
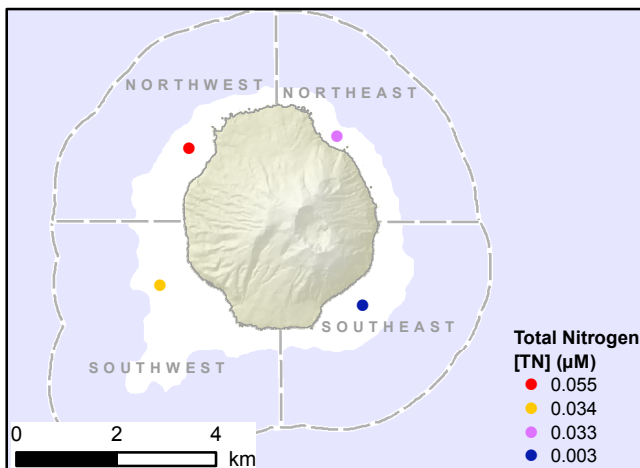
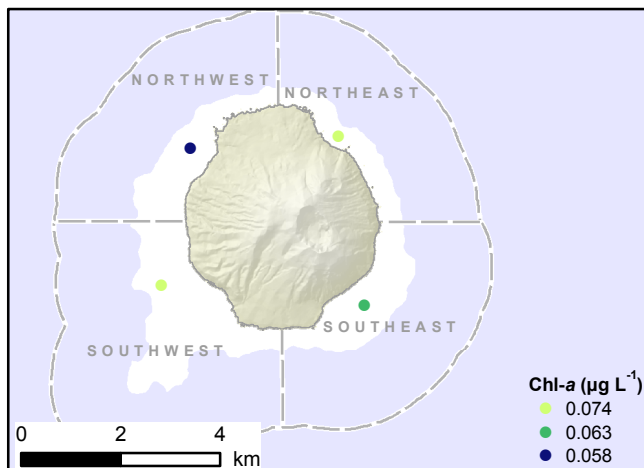


Figure 12.4.1g. Concentrations of (top left) Chl-*a*, (top right) total nitrogen, (middle left) nitrate, (middle right) nitrite, (bottom left) phosphate, and (bottom right) silicate at a 10-m depth, from water samples collected at Alamagan on May 28 during MARAMP 2007.

Temporal Comparison

Temporal comparisons of shallow-water CTD data collected during MARAMP 2003, 2005, and 2007 suggest a dynamic physical oceanographic environment. In 2003 and 2005, moderate and little, respectively, variability was observed both spatially and vertical variability. In comparison, in 2007, variance in water properties was greater in vertical comparisons than in spatial comparisons. Data from both MARAMP 2003 and 2007 show east–west patterns in temperature values, although differences in temperature were greater in 2007, and the pattern observed in 2005 was the reverse of the one seen in 2007. Recorded temperatures were much lower in 2007 than in either of the previous 2 MARAMP survey years. Data were not collected with respect to a specific tidal cycle, which could be a source of oceanographic variability. Likewise, hydrographic variation between MARAMP survey years is likely a result of differences in season. MARAMP 2007 occurred in May, and MARAMP 2003 and 2005 occurred in September.

12.4.2 Time-series Observations

Between 2003 and 2007, subsurface temperature recorders (STRs) were moored at Alamagan to collect time-series observations of temperature, a key oceanographic parameter influencing reef conditions (Fig. 12.4.2a). The locations, depths, time frames, and other details about these deployments are provided in Figures 12.4.2a and b.

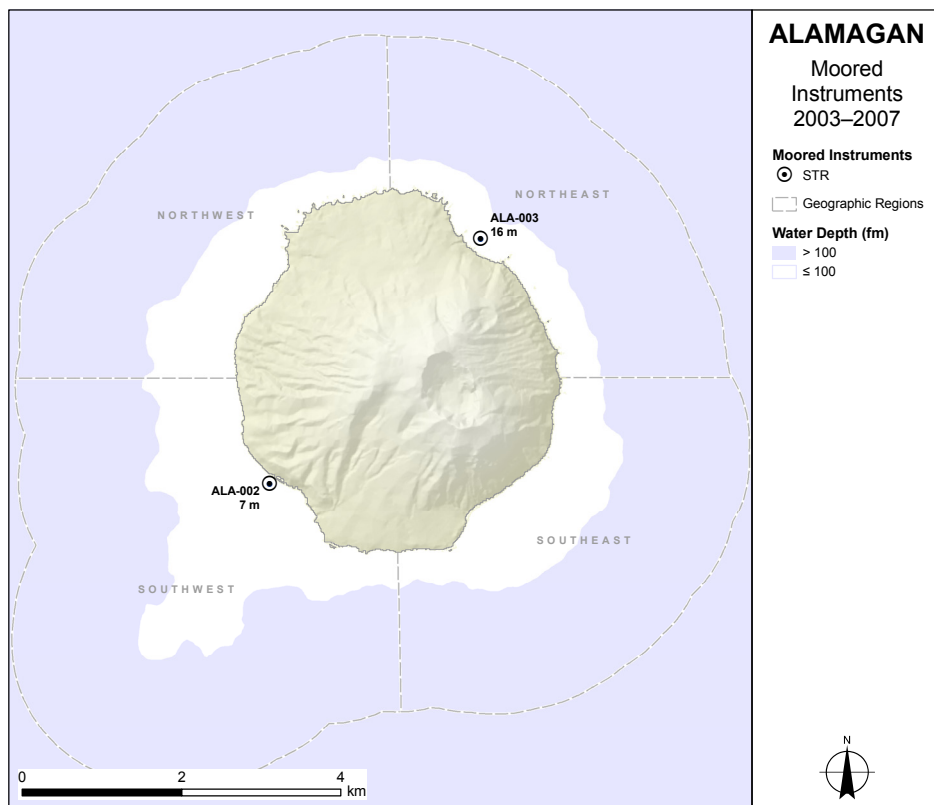


Figure 12.4.2a. Locations and depths of the STRs deployed at Alamagan during MARAMP 2003, 2005, and 2007.

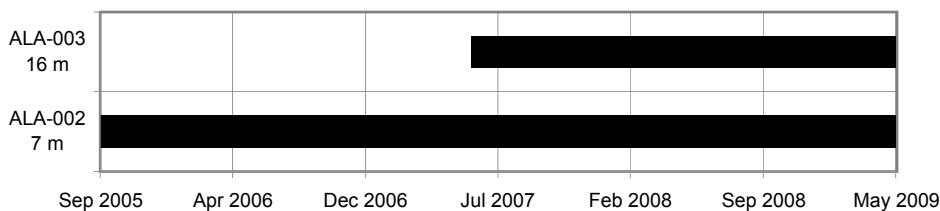
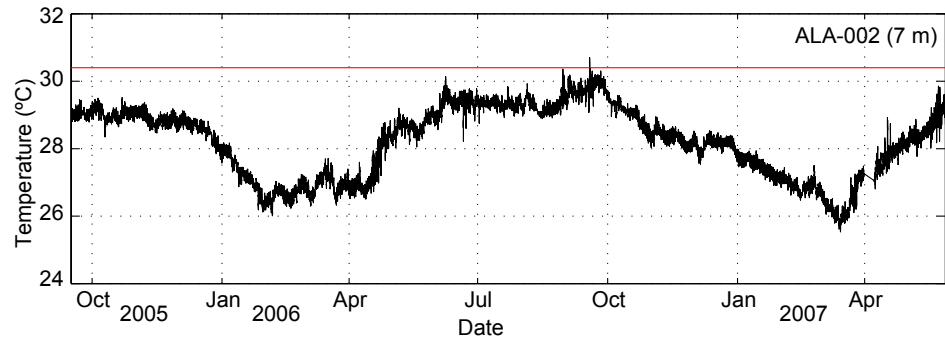


Figure 12.4.2b. Deployment timelines and depths of the STRs moored at Alamagan during the period from September 2005 and May 2009. A solid bar indicates the period for which data were collected by a single STR (ALA-003) or a series of STRs (ALA-002) deployed and retrieved at each mooring site. For more information about deployments and retrievals, see Table 12.2b in Section 12.2: “Survey Effort.”

Temperature data from an STR moored at a depth of 7 m in the southwest region during the period from September 2005 to May 2007 exhibit seasonal temperature variability $\sim 4^{\circ}\text{C}$ between summer and winter months (Fig. 12.4.2c). Water temperatures reached $\sim 30^{\circ}\text{C}$ during the months of June–October and fell to a low of $\sim 25^{\circ}\text{C}$ during the months of January–May. Daily temperature excursions of $\sim 0.2^{\circ}\text{C}$ were recorded throughout this temperature time series, owing to diel heating and cooling of the water column. Temperatures in September 2006 reached the coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean, although this event was relatively brief, lasting less than 1 d.

Figure 12.4.2c. Time-series observations of temperature over the period between September 2005 and May 2007 collected from 1 STR deployed at a depth of 7 m at mooring site ALA-002 (see Figure 12.4.2a for mooring locations). The red line indicates the satellite-derived coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean.



12.4.3 Wave Watch III Climatology

Seasonal wave climatology for Alamagan (Fig. 12.4.3a) was derived using the NOAA Wave Watch III model for the period of January 1997 to May 2008, and seasons were selected to elucidate waves generated by typhoons, which most frequently occur during the period of August–December (for information about the Wave Watch III model, see Chapter 2: “Methods and Operational Background,” Section 2.3.7: “Satellite Remote Sensing and Ocean Modeling”). The wave regime near Alamagan during typhoon season was dominated by trade wind swells characterized by frequent (> 30 d per season), short-period (8–10 s), relatively small (2–3 m) wave events originating from the east ($\sim 80^{\circ}$ – 100°). Superimposed with these short-period swells were large (> 5 m), long-period (12–16 s) wave events from the south (160° – 190°) and south-southeast (200° – 210°). These large, episodic waves primarily were generated by typhoons and occurred on annual to interannual time scales. Additionally, infrequent (~ 5 d per season), long-period (12–14 s) swells with moderate (2.5–3.5 m) wave heights could occur from any direction and likely were associated with episodic, medium-sized, or distant storms. The wave climate outside the typhoon season (February–June) also was characterized by frequent (> 30 d per season) and short-period (~ 8 s) trade wind swells with relatively small (~ 2 m) wave heights originating from the east. Infrequent (< 5 d per season), long-period (12–14 s) swells with moderate (~ 2 – 3 m) wave heights also occurred during this time and could originate from any direction.

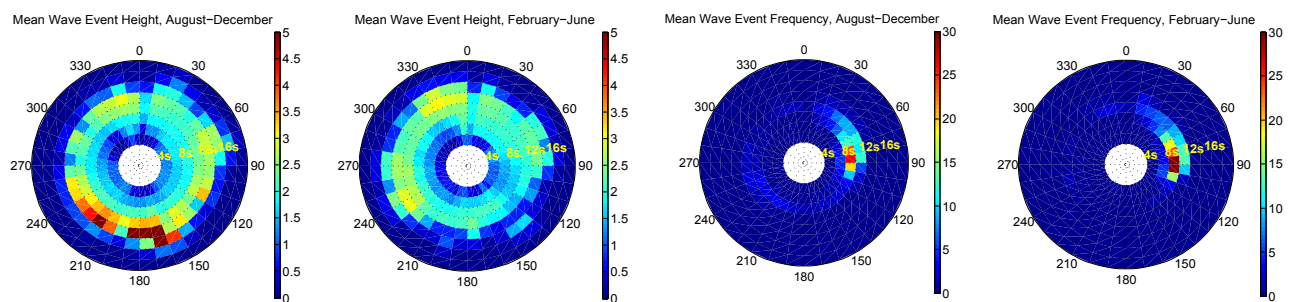


Figure 12.4.3a. NOAA Wave Watch III directional wave climatology for Alamagan from January 1997 to May 2008. This climatology was created by binning (6 times daily) significant wave height, dominant period, and dominant direction from a box ($1^{\circ} \times 1^{\circ}$) centered on Alamagan ($17^{\circ}36' \text{ N}$, $145^{\circ}50' \text{ E}$). Mean significant wave height (*far left and left*), indicated by color scale, for all observations in each directional and frequency bin from August to December (typhoon season) and from February to June. The transition months of January and July are omitted for clarity. Mean number of days (*right and far right*) that conditions in each directional and frequency bin occurred in each season, indicated by color scale; for example, if the color indicates 30, then, on average, the condition occurred during 30 of the 150 days of that season.

12.5 Corals and Coral Disease

12.5.1 Coral Surveys

Coral Cover and Colony Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats around the island of Alamagan was 18% (SE 1.4). Coral cover was variable around Alamagan, with the lowest value reported in the southwest region (Fig. 12.5.1a, top panel).

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats around Alamagan was 17% (SE 1.5). Coral cover was variable around this island, with a localized area of high cover, relative to other survey areas at Alamagan, observed in the northeast region over 9 survey segments with a mean of 31% (Fig. 12.5.1a, middle panel). Towed divers during MARAMP 2005 recorded estimates of stressed-coral cover, including corals that were fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: “Methods and Operational Background,” Section 2.4.5, “Corals and Coral Disease”). Overall, 0.4% (SE 0.04) of coral cover observed on forereef habitats around Alamagan appeared stressed. Estimates of stressed-coral cover from towed-diver surveys was low for the majority of reefs surveyed around Alamagan in 2005.

From MARAMP 2007 towed-diver surveys, mean cover of live hard corals on forereef habitats around Alamagan was 22% (SE 1.6). Coral cover was variable around Alamagan, with the highest coral cover found in the northwest region, for 8 segments with a mean of 38% (Fig. 12.5.1a, bottom panel). Overall, 1% (SE 0.57) of coral cover observed on forereef habitats around this island appeared stressed in 2007. Estimates of stressed-coral cover from towed-diver surveys conducted in 2007 were low for the majority of reefs surveyed around this island.

During MARAMP 2007, 3 REA benthic surveys using the line-point-intercept method were conducted on forereef habitats around Alamagan. Site-specific estimates of live-hard-coral cover from these surveys ranged from 16.7% to 33.3% with an overall sample mean of 23.5% (SE 5). Coral cover was highest at REA site ALA-03 in the southwest region and lowest at ALA-01 in the northeast region (Fig. 12.5.1b, bottom panel).

During MARAMP 2003, 3 REA benthic surveys using the quadrat method on forereef habitats at Alamagan documented 379 coral colonies within a survey area of 11.25 m². Site-specific coral-colony density ranged from 32 to 36.3 colonies m⁻² with an overall sample mean of 33.7 colonies m⁻² (SE 1.3) at Alamagan. The highest colony density was recorded at ALA-01 in the northeast region, and the lowest colony density was observed at ALA-02 in the northwest region (Fig. 12.5.1b, top panel).

During MARAMP 2005, 3 REA benthic surveys using the quadrat method on forereef habitats at Alamagan documented 646 coral colonies within a survey area of 12 m². Site-specific coral-colony density ranged from 50.8 to 55.6 colonies m⁻² with an overall sample mean of 53.8 colonies m⁻² (SE 1.5). The highest colony density was recorded at ALA-02 in the northwest region, and the lowest colony density was observed at ALA-01 in the northeast region (Fig. 12.5.1b, middle panel).

During MARAMP 2007, 3 REA benthic surveys using the quadrat method on forereef habitats at Alamagan documented 583 coral colonies within a survey area of 12 m². Site-specific coral-colony density ranged from 41 to 53.8 colonies m⁻², with an overall sample mean of 48.6 colonies m⁻² (SE 3.9). Similar to survey results in 2005, the highest colony density was recorded at ALA-02 in the northwest region, and the lowest colony density was observed at ALA-01 in the northeast region (Fig. 12.5.1b, bottom panel).

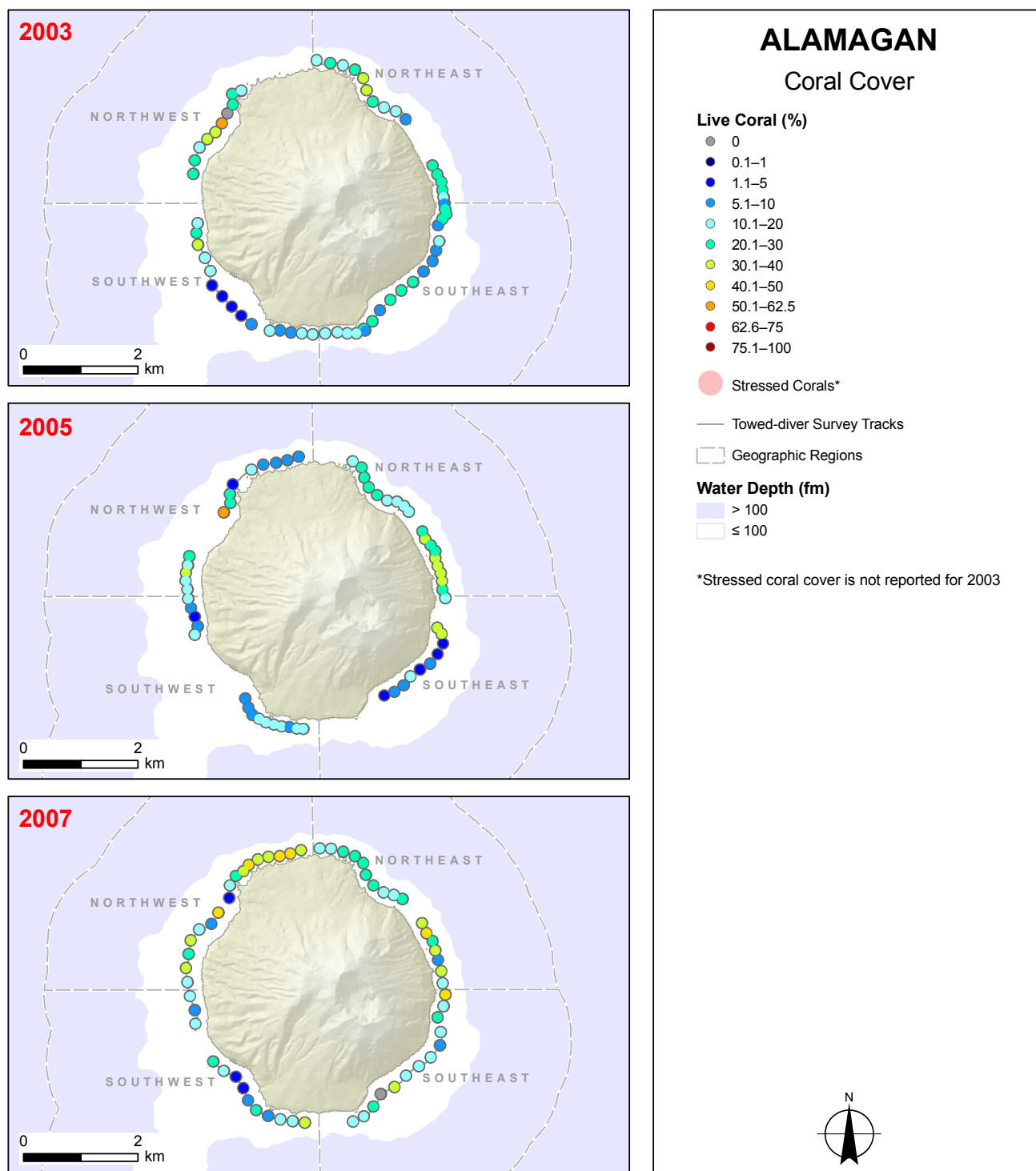


Figure 12.5.1a. Cover (%) observations of live hard corals from towed-diver benthic surveys of forereef habitats conducted around Alamagan during MARAMP 2003, 2005, and 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of $\sim 200 \times 10$ m (~ 2000 m²). Pink symbols are shown only for segments where stressed-coral cover was > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005 and 2007.

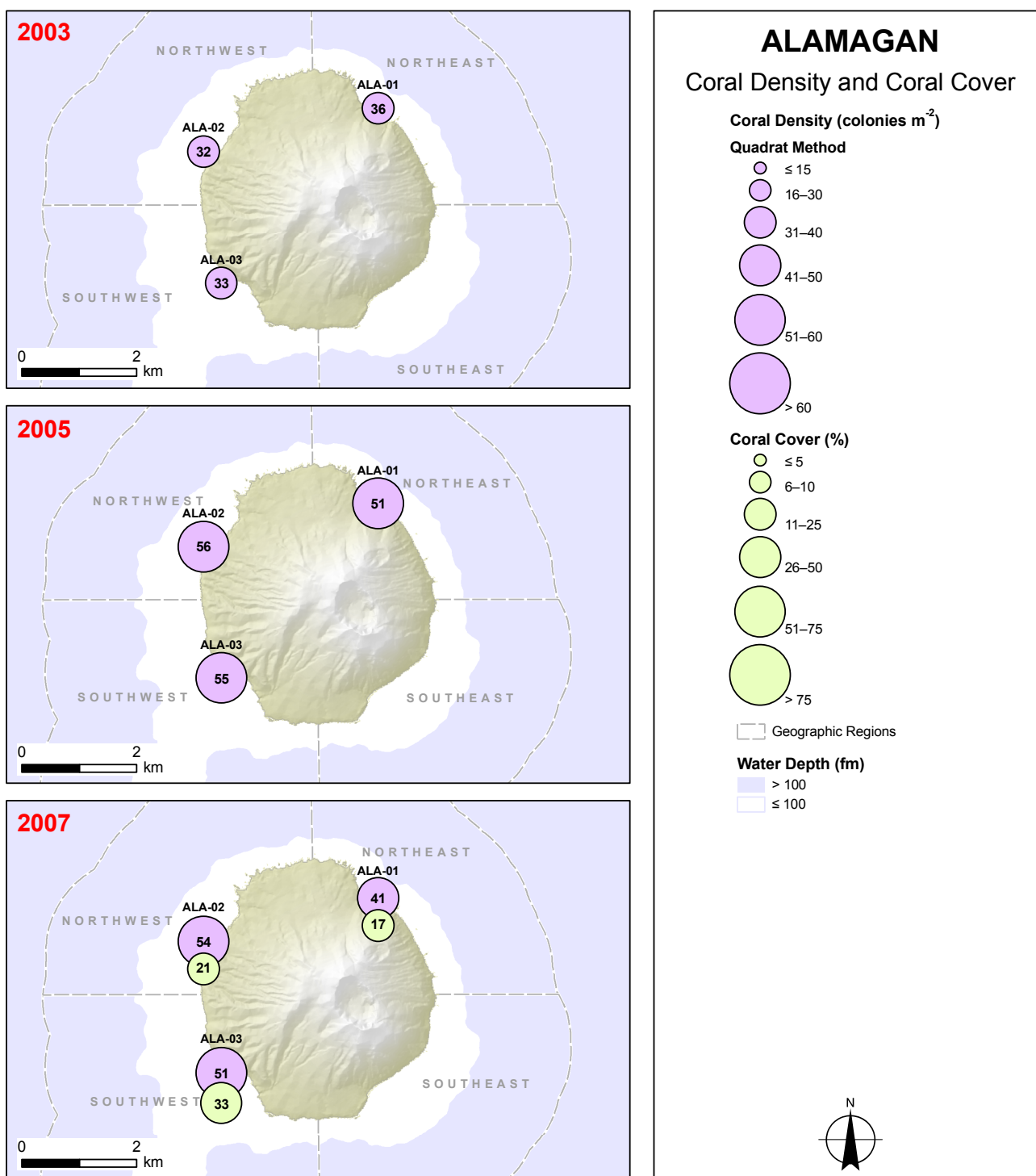


Figure 12.5.1b. Colony-density (colonies m⁻²) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Alamagan during MARAMP 2003, 2005, and 2007 and cover (%) observations of live corals from REA benthic surveys during MARAMP 2007. Values are provided within each symbol. The quadrat method was used to assess coral-colony density.

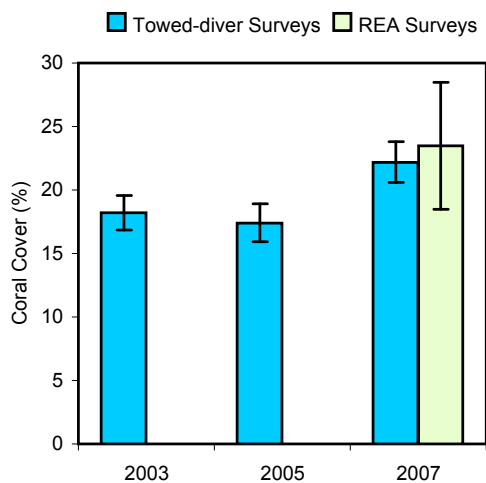


Figure 12.5.1c. Temporal comparison of mean live-coral-cover (%) values from REA and towed-diver benthic surveys conducted on forereef habitats around Alamagan during MARAMP 2003, 2005, and 2007. No REA coral-cover surveys using the line-point-intercept method were conducted around Alamagan in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

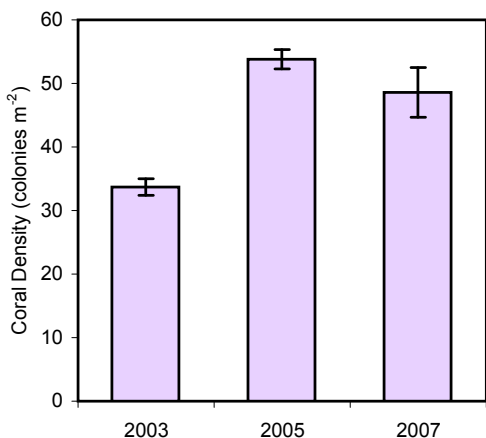


Figure 12.5.1d. Temporal comparison of mean coral-colony densities (colonies m⁻²) from REA benthic surveys conducted on forereef habitats at Alamagan during MARAMP 2003, 2005, and 2007. The quadrat method was used in the 3 survey years to measure coral-colony density. Error bars indicate standard error (± 1 SE) of the mean.

the total number of colonies enumerated at Alamagan in 2005. All other genera individually accounted for < 10% to the total number of colonies. The genus *Astreopora* dominated the coral fauna at ALA-03 in the southwest region, contributing 24% of the total number of colonies recorded at that site, as well as at ALA-02, contributing 21.2% of the total colonies at that site. The genus *Montipora* dominated the coral fauna at ALA-01, contributing 18.7% of the total number of colonies observed at that site.

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Alamagan during MARAMP 2007, and 23 coral genera were observed at Alamagan. Generic richness ranged from 14 to 19 with a mean of 17.3 (SE 1.7) genera per site. The highest generic diversities were seen at ALA-01 and ALA-03 in the northeast and southwest regions, and the lowest generic diversity was observed at ALA-02 in the northwest region (Fig. 12.5.1e, bottom panel). Similar to survey results in 2003 and 2005, *Astreopora*, *Favia*, and *Pavona* were the most numerically abundant genera, contributing 17.1%, 15.5%, and 15.6% of the total number of colonies enumerated at Alamagan in 2007. All other genera individually

Islandwide mean cover of live hard corals, estimated from towed-diver surveys of forereef habitats, varied little between MARAMP survey years, ranging from 18% (SE 1.4) and 17% (SE 1.5) in 2003 and 2005 to 22% (SE 1.6) in 2007 (Fig. 12.5.1c). The spatial variation between the 3 MARAMP towed-diver survey efforts reasonably accounts for the relatively small variation in mean live-coral-cover values between survey years. Estimates of coral cover from REA surveys were similar to towed-diver survey results, with an overall sample mean of 23.5% (SE 5) for the 3 REA sites surveyed in 2007.

The overall sample mean of coral-colony density from REA benthic surveys of forereef habitats at Alamagan, using the quadrat method, increased from 33.7 colonies m⁻² (SE 1.3) in 2003 to 53.8 colonies m⁻² (SE 1.5) in 2005 and 48.6 colonies m⁻² (SE 3.9) in 2007 (Fig. 12.5.1d). Variation in overall and site-specific density distributions between MARAMP survey years may result from chance differences in quadrat placement, increased recruitment, or fragmentation of existing colonies.

Coral Generic Richness and Relative Abundance

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Alamagan during MARAMP 2003, and 21 coral genera were observed at Alamagan. Generic richness ranged from 12 to 18 with a mean of 15.3 (SE 1.8) coral genera per site. The highest generic diversity was seen at ALA-03 in the southwest region, and the lowest generic diversity was recorded at ALA-02 in the northwest region (Fig. 12.5.1e, top panel). *Favia*, *Pavona*, and *Astreopora* were the most numerically abundant genera, contributing 15.7%, 15.2%, and 14% of the total number of colonies enumerated at Alamagan in 2003. All other genera individually accounted for < 10% of the total number of colonies. The genus *Astreopora* dominated the coral fauna at ALA-02, contributing 26.7% of the total number of colonies recorded at that site. The genus *Pavona* dominated at ALA-03 in the southwest region and the genus *Favia* dominated at ALA-01 in the northeast region, contributing 24.4% and 13.2% to the total number of colonies observed at their respective sites.

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Alamagan during MARAMP 2005, and 23 coral genera were observed at Alamagan. Generic richness ranged from 14 to 21 with a mean of 16.7 (SE 2.2) coral genera per site. The highest generic diversity was seen at ALA-01 in the northeast region, and the lowest generic diversity was observed at ALA-02 in the northwest region (Fig. 12.5.1e, middle panel). *Astreopora*, *Pavona*, and *Favia* were the most numerically abundant genera, contributing 18.7%, 16.9%, and 14.4% of

accounted for < 10% of the total number of colonies. The genus *Astreopora* dominated the coral fauna at ALA-02, contributing 25.1% of the total number of colonies recorded at that site, while *Montipora* (15.9%) and *Favia* (18.6%) were the dominant genera at ALA-01 and ALA-03, respectively.

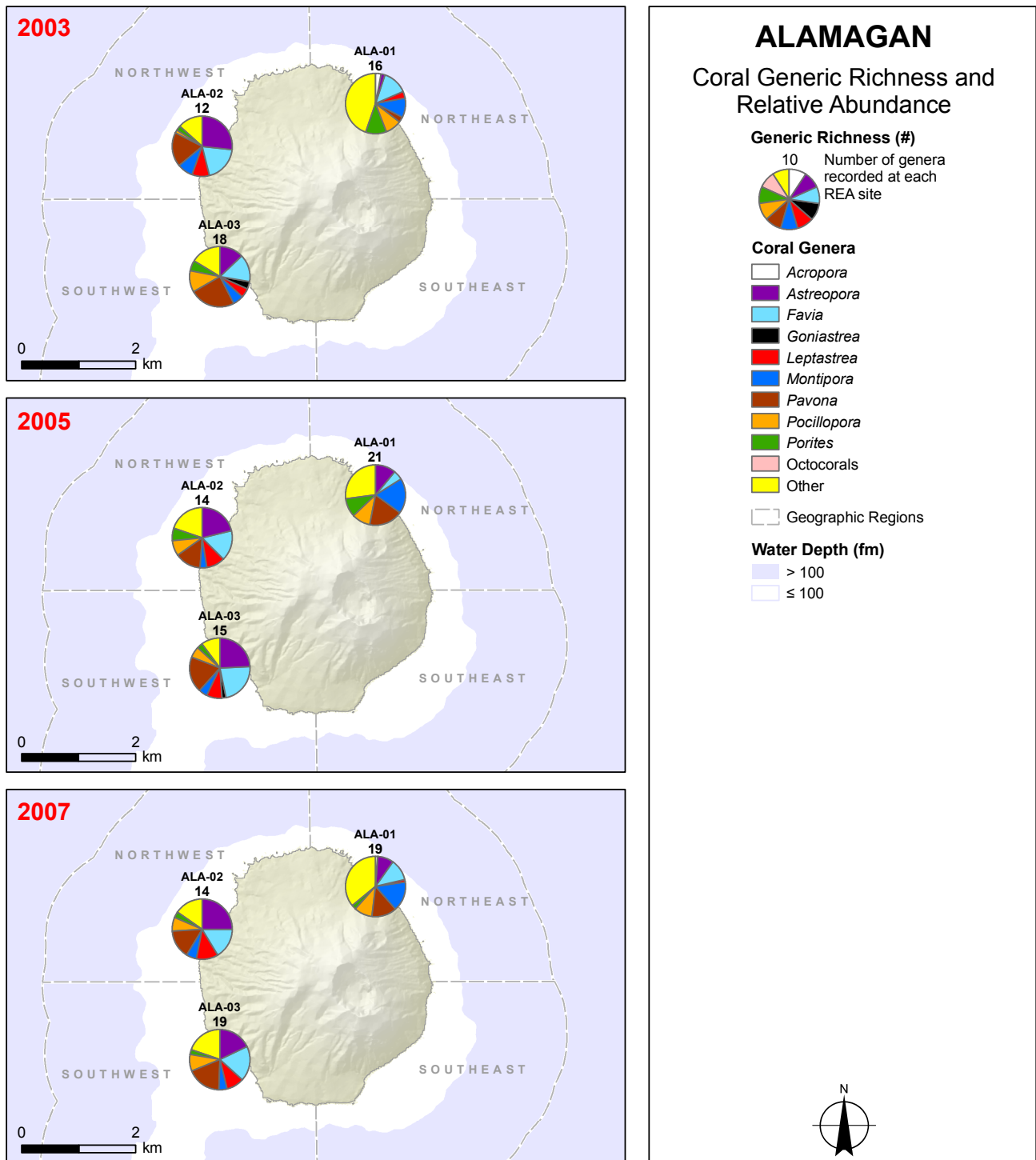


Figure 12.5.1e. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Alamagan during MARAMP 2003, 2005, and 2007. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in the 3 survey years to survey coral genera.

Site-specific estimates of generic richness across the 3 MARAMP survey years ranged from 12 to 21 on forereef habitats at Alamagan. Overall sample means of generic richness remained similar between the 3 survey years with 15.3 (SE 1.8) in 2003, 16.7 (SE 2.2) in 2005, and 17.3 (SE 1.7) in 2007 (Fig. 12.5.1f). There were more genera observed at Alamagan in 2005 and 2007 than in 2003 overall and at individual sites. The quadrat method was used during the 3 survey years to assess generic richness.

Across the 3 MARAMP survey years, 25 coral genera were observed on forereef habitats at Alamagan. The genera *Astreopora*, *Pavona*, and *Favia* were important components of the coral fauna at Alamagan, contributing > 10% of the total number of colonies enumerated in the 3 survey years. The genus *Astreopora* was the most numerically abundant taxon in 2005 and 2007 and the third-most abundant taxon in 2003, contributing 18.7%, 17.1%, and 14% of the total number of colonies enumerated in each survey year. The genus *Favia* was the most numerically abundant taxon in 2003 and the third-most abundant taxon in 2005 and 2007, accounting for 15.7%, 14.4%, and 15.5% of the total number of colonies enumerated in each survey period. The genus *Pavona* was the second-most numerically abundant taxon in the 3 survey years, contributing 15.2%, 16.9%, and 15.6% of the total number of colonies enumerated. All other taxa individually contributed < 10% of the total number of colonies enumerated across the 3 survey years.

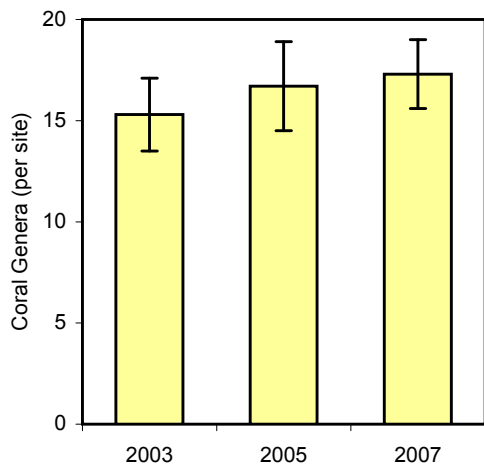


Figure 12.5.1f. Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats at Alamagan during MARAMP 2003, 2005, and 2007. The quadrat method was used in the 3 survey years to survey coral genera. Error bars indicate standard error (± 1 SE) of the mean.

Coral Size-class Distribution

During MARAMP 2003, 3 REA benthic surveys of forereef habitats were conducted at Alamagan using the quadrat method. The coral size-class distributions from these surveys shows that the majority (60.8%) of corals had maximum diameters ≤ 5 cm. The next 4 size classes (6–10, 11–20, 21–40, and 41–80 cm) accounted for 27.7%, 8.2%, 2.9% and 0.5% of colonies recorded. No colonies with maximum diameters > 80 cm were recorded. At each REA site, a majority (> 52%) of corals were in the smallest size class (0–5 cm; Fig. 12.5.1g, top panel).

During MARAMP 2005, 3 REA benthic surveys of forereef habitats were conducted at Alamagan using the quadrat method. The coral size-class distributions from these surveys shows that the majority (69.7%) of corals had maximum diameters ≤ 5 cm. The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 19.7%, 9.6%, and 1.1% of colonies recorded. No colonies with maximum diameters > 40 cm were recorded. At each REA site, a majority (> 60%) of corals were in the smallest size class (0–5 cm; Fig. 12.5.1g, middle panel).

During MARAMP 2007, 3 REA benthic surveys of forereef habitats were conducted at Alamagan using the quadrat method. The coral size-class distributions from these surveys shows that the majority (65.1%) of corals had maximum diameters ≤ 5 cm. The next 4 size classes (6–10, 11–20, 21–40, and 41–80 cm) accounted for 24.4%, 6.3%, 4% and 0.2% of colonies recorded. No colonies with maximum diameters > 80 cm were recorded. At each REA site, a majority (> 56%) of corals were in the smallest size class (0–5 cm; Fig. 12.5.1g, bottom panel).

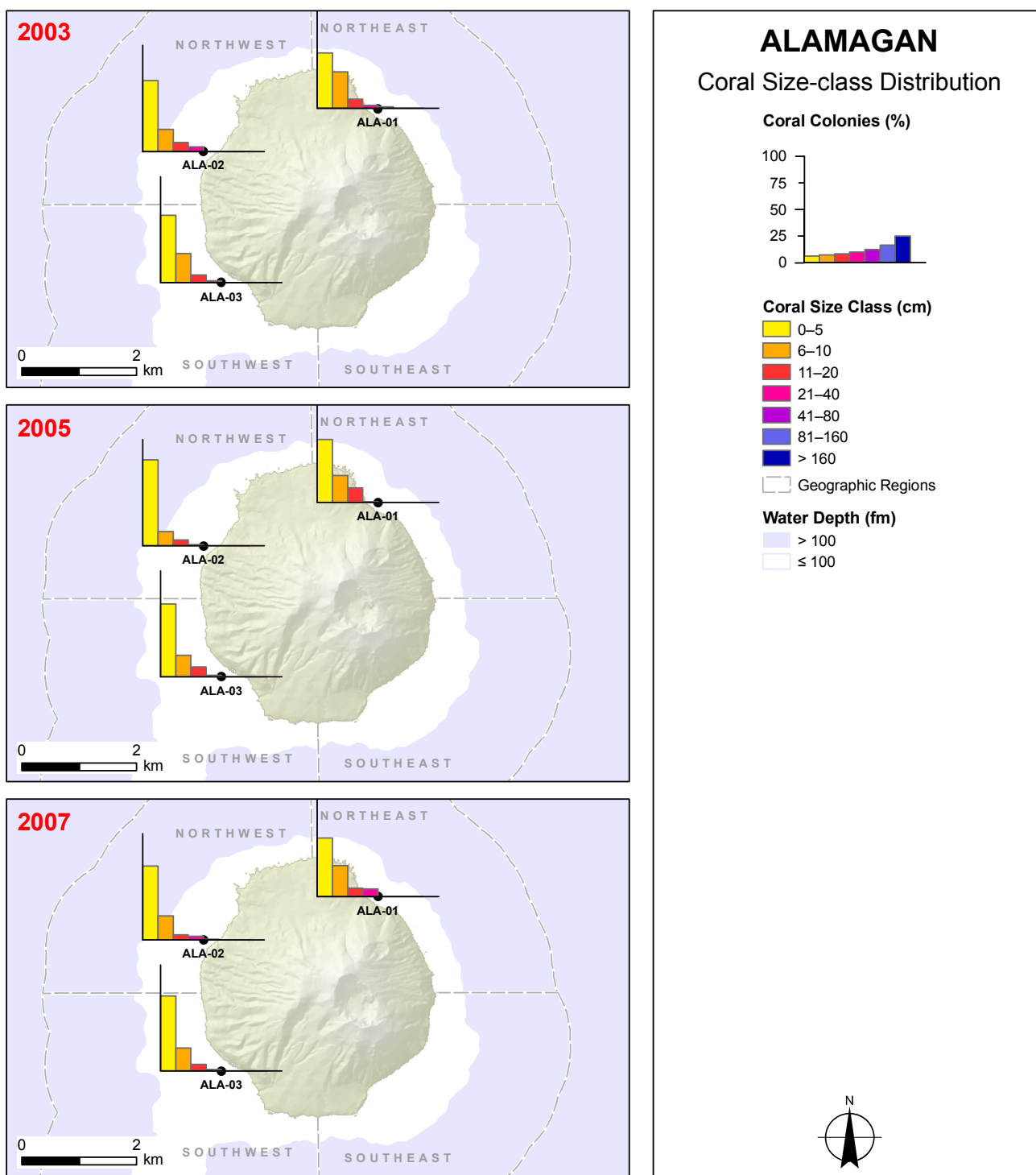
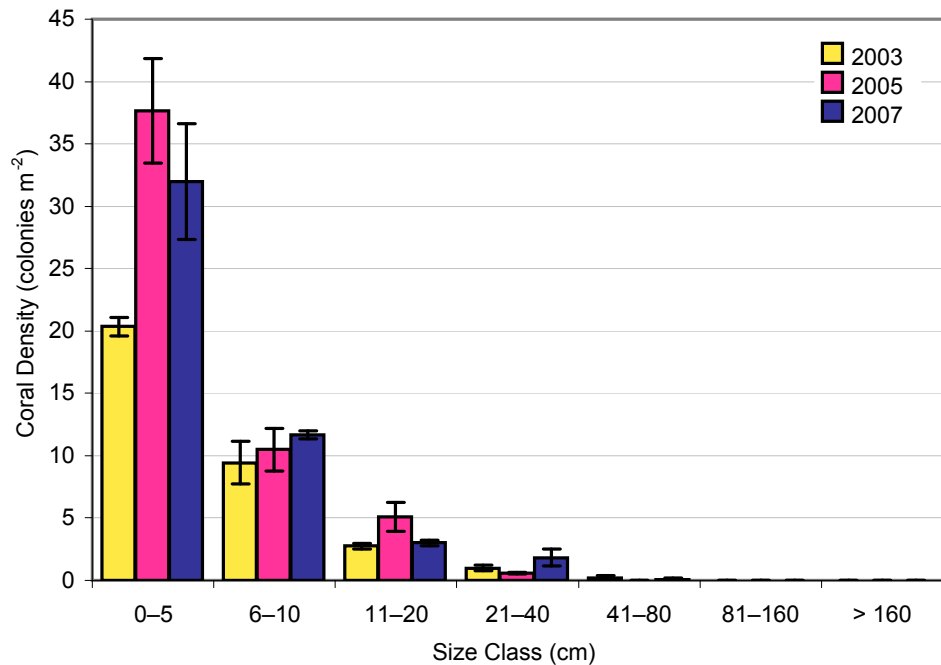


Figure 12.5.1g. Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Alamagan during MARAMP 2003, 2005 and 2007. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in the 3 survey years to size corals.

Site-specific distributions of coral size classes reflect inherent biases in the quadrat method used to census and size corals. Corals whose center fell within the borders of a quadrat (50×50 cm) were tallied and measured in 2 planar dimensions to the nearest centimeter. Fewer large colonies than small colonies can fall within a quadrat. This bias can contribute to higher counts of colonies in the smallest size classes and lower counts of colonies in the largest size classes compared to the actual relative colony densities. At each site, 15 or 16 such quadrats were examined (total survey area = 3.75 or 4 m²), enabling observers to closely inspect and record each coral colony within the quadrat. For more on this survey method, see Chapter 2: “Methods and Operational Background,” Section 2.4.5: “Corals and Coral Disease.”

In each of 3 MARAMP survey years, the number of coral colonies censused on forereef habitats at Alamagan was > 20 colonies m⁻² in the smallest size class (0–5 cm; Fig. 12.5.1h). The overall sample mean proportion of colonies that fell in the smallest size class varied between MARAMP survey years, as did site-specific size-class distributions. Concomitantly, the overall sample mean and site-specific proportions of colonies in all other size classes fluctuated between years. That coral colonies fell in the smallest size class with greater frequency than in other size classes is likely an outcome of recruitment or fragmentation of existing colonies, while minor variation between survey years in overall and site-specific size-class distributions likely results from chance differences in individual quadrat placements.

Figure 12.5.1h. Mean coral-colony densities (colonies m⁻²) by size-class from REA benthic surveys of forereef habitats conducted at Alamagan during MARAMP 2003, 2005, and 2007. The quadrat method was used in all 3 years to size corals. Error bars indicate standard error (± 1 SE) of the mean.



12.5.2 Surveys for Coral Disease and Predation

During MARAMP 2007, REA benthic surveys for coral disease and predation were conducted at 3 sites on forereef habitats at Alamagan, covering a total area of 900 m². Six cases of disease were detected, translating to an overall mean prevalence of 0.01% (SE 0.01). Coral-colony counts at all REA sites at Alamagan were conducted using the quadrat method, resulting in high coral-colony densities and, therefore, low disease prevalence values, relative to the levels found at sites at other islands surveyed using the belt-transect method.

Two major disease conditions and other syndromes were observed at Alamagan (Fig. 12.5.2a). The most abundant disease state was bleaching, followed by subacute tissue loss and other syndromes, particularly infestation and overgrowth by the encrusting sponge *Terpios*. All 3 sites contained disease; however, low prevalence values were observed (Fig. 12.5.2b). Four cases of bleaching were recorded at ALA-02 and ALA-03 on coral species of the genera *Plesiastrea*, *Echinopora*, and *Platygyra*. At both ALA-01 and ALA-03, only 1 case of tissue loss and 1 case of sponge overgrowth were detected on colonies of *Goniastrea*. No signs of predation scars from crown-of-thorns seastars (*Acanthaster planci*) or corallivorous snails, such as snails from the genus *Drupella*, were documented at Alamagan.

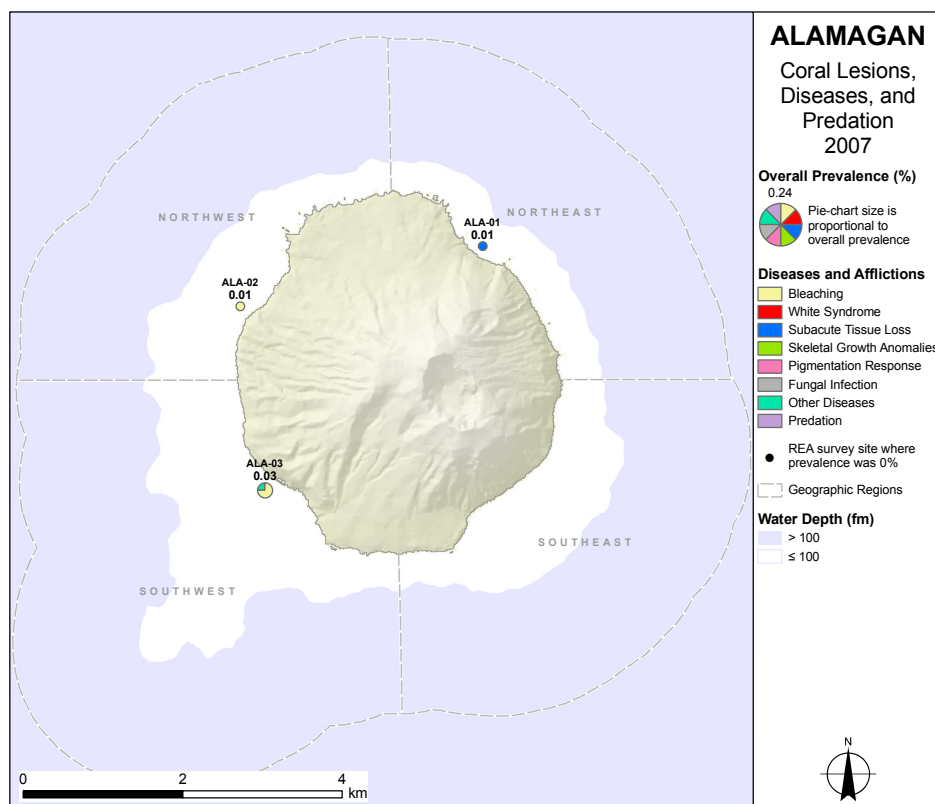


Figure 12.5.2a. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted at Alamagan during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The color-coded portions of the pie charts indicate disease-specific prevalence.

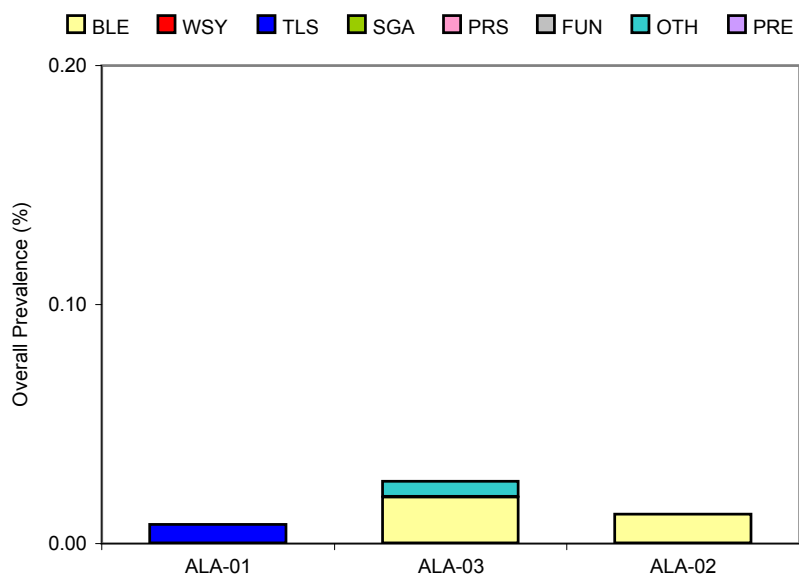


Figure 12.5.2b. Overall prevalence (%) observations of coral diseases and predation from REA benthic surveys of forereef habitats conducted at Alamagan during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at each REA site. The order of conditions presented in the bars is the same as the order in the legend. BLE: bleaching; WSY: white syndrome; TLS: subacute tissue loss; SGA: skeletal growth anomalies; PRS: pigmentation response; FUN: fungal infections; OTH: algal and cyanophyte infections and other lesion of unknown etiology; PRE: predation by crown-of-thorns seastars or corallivorous snails.

12.6 Algae and Algal Disease

12.6.1 Algal Surveys

Algal Cover: Macroalgae and Turf Algae

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats around the island of Alamagan was 41% (SE 2.3). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The survey with the highest mean macroalgal cover of 52% occurred on the east side of this island and crossed the border between the northeast and southeast regions (Fig. 12.6.1a, top left panel). During this survey, habitat complexity was medium and the habitat types observed consistently were rubble (noted on more than half of the segments from this 5-min survey) and pavement. The 3 next-greatest values of mean macroalgal cover were found on the east and south sides of this island. The survey completed on the south side across the border of the southeast and southwest regions had a mean macroalgal cover of 45%, and the other 2 surveys conducted on the east side, in the southeast and northeast regions, each had a mean cover of 44%. The lowest mean macroalgal cover of 27% was recorded during the survey completed entirely in the southwest region.

TOAD surveys completed at Alamagan during MARAMP 2003 were conducted at depths of 45–280 m. Analyses of TOAD video footage obtained from 6 surveys suggested that there were almost no macroalgae in the northwest and southeast regions at least as seen in a majority of images; only 2 analyzed video frames showed any macroalgae at all, with cover of 20%. In contrast, analyses of video footage collected southwest of Alamagan suggested that, although much of the areas surveyed had little or no macroalgae, some of the areas surveyed had macroalgal cover of 20%–100%, with the highest macroalgal cover occurring at depths of 70–97 m. (Fig. 12.6.1a, top left panel).

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on forereef habitats around Alamagan was 26% (SE 2.7). The survey with the highest mean macroalgal cover of 52% occurred in the southern part of the southwest region (Fig. 12.6.1a, middle left panel). For 9 of the 10 segments of this survey, habitat complexity was described as medium-low or medium. The second-greatest macroalgal cover of 45% was observed in the southern part of the northeast region, and the lowest mean macroalgal cover of 1% was recorded in the southeast region.

From MARAMP 2007 towed-diver surveys, mean cover of macroalgae on forereef habitats around Alamagan was 16% (SE 1.6). The survey with the highest mean macroalgal cover of 29% occurred on the east side of this island and crossed the border between the northeast and southeast regions (Fig. 12.6.1a, bottom left panel). Habitat in this area was documented mostly as medium or medium-high, and species of the calcified green macroalgal genus *Halimeda* were observed on each of the first 6 survey segments. The lowest mean macroalgal cover of 9% was recorded during a survey in the northwest region, and continuous reef and a moderate slope were noted for most of this survey's segments.

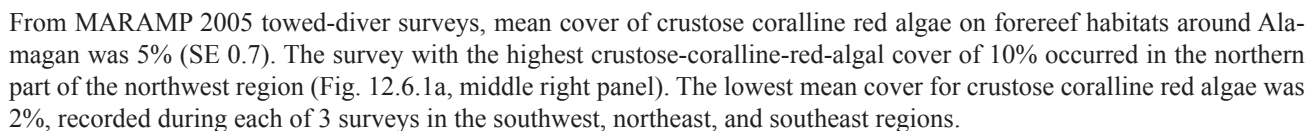
During MARAMP 2007, 3 REA benthic surveys of forereef habitats at Alamagan were conducted using the line-point-intercept method. Site-specific estimates of macroalgal cover ranged from 2.9% to 12.7% with an overall sample mean of 9% (SE 3.1). The survey with the highest macroalgal cover occurred in the northwest region at REA site ALA-02 (Fig. 12.6.1b). The lowest macroalgal cover was recorded in the southwest region at ALA-03.

Turf-algal cover from these REA surveys ranged from 43.1% to 56.9% with an overall sample mean of 50% (SE 4). The highest turf-algal cover of 56.8% occurred at ALA-01 in the northeast region (Fig. 12.6.1b). Turf-algal cover was 50% in the southwest region at ALA-03 and 43.1% in the northwest region at ALA-02.

Algal Cover: Crustose Coralline Red Algae

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Alamagan was 7% (SE 1.1). The survey with the highest crustose-coralline-red algal cover of 25% occurred in the northern part of the northeast region (Fig. 12.6.1a, top right panel). The lowest crustose-coralline-red-algal cover of 1% was recorded during 2 surveys: 1 survey completed from the southeast to the southwest region, and 1 survey completed entirely in the southwest region. The 2 next-lowest values for mean cover were 2% and 3%, found during surveys completed in the northwest region and in the northern part of the southwest region.

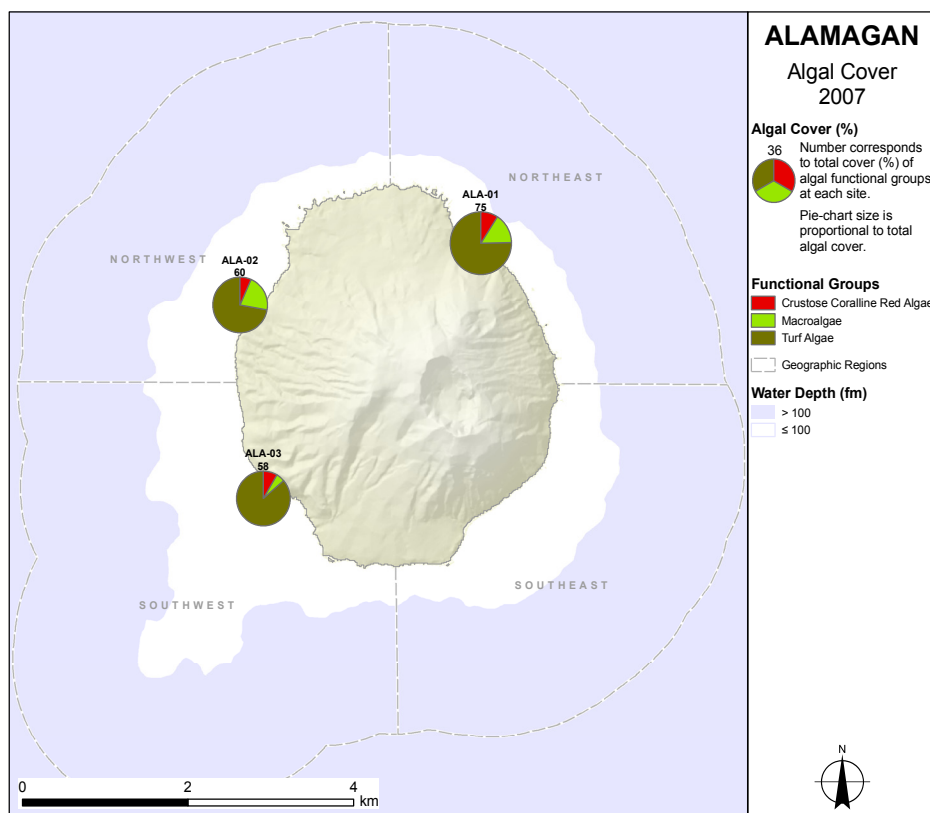
Analyses of TOAD video footage obtained from the 6 surveys conducted during MARAMP 2003 suggested that there were no crustose coralline red algae in the surveyed areas, at least as observable from images.



From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Alamagan was 10% (SE 0.9). The survey with the highest crustose-coralline-red-algal cover of 19% occurred in the northern part of the northwest region (Fig. 12.6.1a, bottom right panel). For this survey, the habitat was described as continuous reef of mostly medium-high complexity. The lowest mean cover for crustose coralline red algae of 5% was recorded in the southwest region.

During MARAMP 2007, 3 REA benthic surveys of forereef habitats around Alamagan were conducted using the line-point-intercept method. Site-specific estimates of crustose-coralline-red algal cover ranged from 3.9% to 6.9% with an overall sample mean of 5% (SE 0.9). The survey with the highest mean cover of crustose coralline red algae occurred in the northeast region at ALA-01 (Fig. 12.6.1b). The lowest crustose-coralline-red-algal cover was recorded at ALA-02 in the northwest region.

Figure 12.6.1b. Observations of algal cover (%) from REA benthic survey of forereef habitats conducted using the line-point-intercept method at Alamagan during MARAMP 2007. The pie charts indicate algal cover by functional group, and values of total algal cover are provided above each symbol.



Algal Cover: Temporal Comparison

Between MARAMP 2005 and 2007, islandwide mean cover of macroalgal populations around Alamagan, based on towed-diver surveys of forereef habitats, appeared to decrease from 26% (SE 2.7) in 2005 to 16% (SE 1.6) in 2007 (Fig. 12.6.1c). When considering survey results, keep in mind that turf algae were included, along with macroalgae, in towed-diver surveys of macroalgal cover only in 2003. Other factors, such as a change in season between survey periods, could have contributed to differences in macroalgal cover (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

Some of the highest levels of macroalgal cover found around Alamagan were observed consistently on the east side of this island exhibited. During each MARAMP survey year, a towed-diver survey crossed the border of the northeast and southeast regions, recording the highest macroalgal cover in 2003 and 2007 and the second-greatest value in 2005.

Crustose-coralline-red-algal populations around Alamagan, based on towed-diver survey of forereef habitats, had average cover values $\leq 10\%$ during each of the 3 MARAMP survey years (Fig. 12.6.1c). Islandwide mean cover of crustose coralline red algae increased to 10% (SE 0.9) in 2007, when surveys were conducted in May, from 5% (SE 0.7) in 2005 and 7% (SE 1.1) in 2003.

The lowest mean cover of crustose coralline red algae around Alamagan was found consistently in the southern part of the southwest region during towed-diver surveys in each of the 3 survey years. The highest mean crustose-coralline-red algal cover was recorded in the northeast region in 2003 but in the northern part of the northwest region in 2005 and 2007.

Macroalgal Genera and Functional Groups

In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites is about 90% complete for the northern islands of the Mariana Archipelago with hundreds of species identified so far. Ultimately, based on this microscopic analysis, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA benthic surveys were conducted at 3 sites on forereef habitats at Alamagan. In the field, 9 macroalgal genera (3 red, 5 green, and 1 brown), containing at least 10 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. ALA-01 in the northeast region had the highest macroalgal generic diversity with 7 genera, containing 7 species, documented in the field. The lowest macroalgal generic diversity was found in the southwest region at ALA-03 with 3 species representing 3 genera recorded.

Species of the green algal genera *Chlorodesmis* and *Halimeda* were equally abundant and the most dominant taxa at Alamagan in 2003, occurring in 52.8% of the sampled photoquadrats. Of the 10 macroalgal species tentatively identified in the field, only a select few showed any spatial patterns of distribution. *Halimeda taenicola* and species of *Chlorodesmis* frequently were found at 2 sites on the west side of Alamagan, occurring in 50% and 83.3% of photoquadrats sampled at ALA-02 and in 100% and 75% of photoquadrats sampled at ALA-03 (Fig. 12.6.1d, top panel). At ALA-01 in the northeast region, the red algal genus *Amphiroa* and the brown algal genus *Lobophora* were recorded in 33.3% and 41.7% of sampled photoquadrats. Species of the green algal genera *Dictyosphaeria* and *Neomeris*, the red algal genus *Jania*, and an unknown species of *Halimeda* also were observed at ALA-01, all occurring in 8.3% of sampled photoquadrats. Species of the green algal genus *Caulerpa* were not recorded at ALA-01 but were found in 8.3% of photoquadrats sampled at both ALA-02 and ALA-03 in the northwest and southwest regions.

Turf algae and crustose coralline red algae both were exceptionally common in 2003, occurring in 100% and 66.7% of photoquadrats sampled at Alamagan (Fig. 12.6.1d, top panel). Turf-algal communities were ubiquitous at all sites, and although crustose coralline red algae occurred at all sites, the occurrence of this functional group varied within a range of 50%–58.3% at ALA-01 and ALA-02 in the northern regions and 91.7% at ALA-03 in the southwest region. Cyanobacteria, found in 16%–70.8% of sampled photoquadrats, were relatively common.

During MARAMP 2005, REA benthic surveys were conducted at 3 sites on forereef habitats at Alamagan. In the field, 12 macroalgal genera (6 red, 4 green, and 2 brown), containing at least 12 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. ALA-02 in the northwest region had the highest macroalgal generic diversity with 8 genera, each containing only 1 species, documented in the field. The lowest macroalgal generic diversity was found at ALA-03 in the southwest region with 6 species representing 6 genera recorded.

Species of the genus *Halimeda* were the most common macroalgae observed at this island in 2005, occurring in 55.6% of all sampled photoquadrats. Of the 12 macroalgal species tentatively identified in the field, only a select few showed any spatial patterns of distribution. Species of the genus *Halimeda* were recorded only at ALA-02 and ALA-03, in 75% and

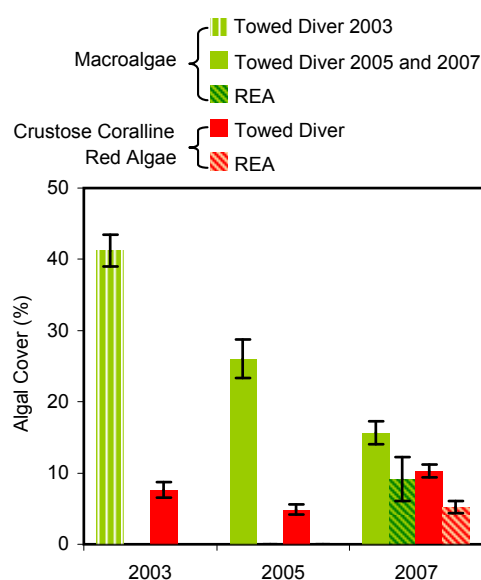


Figure 12.6.1c. Temporal comparison of algal-cover values (%) from surveys conducted on forereef habitats around Alamagan during MARAMP 2003, 2005, and 2007. Macroalgal cover from towed-diver surveys includes turf algae only in 2003. No REA algal-cover surveys using the line-point-intercept method were conducted in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

91.7% of photoquadrats sampled at these sites (Fig. 12.6.1d, middle panel). The genus *Jania* also was common, occurring in 100% of sampled photoquads at ALA-03 in the southwest region and 33.3% at ALA-01 in the northeast region. At ALA-01, the red algal genus *Asparagopsis* and the brown algal genus *Dictyota* were recorded in 58.3% and 41.7% of the sampled photoquadrats. Species of *Amphiroa* and *Chlorodesmis* were observed at fairly high abundance at ALA-02, occurring in 50% and 58.3% of the photoquads sampled at that site. *Caulpera* and *Neomeris* were the only algal genera recorded at all sites in 2005, occurring in 8.3% and 16.7% of photoquadrats sampled.

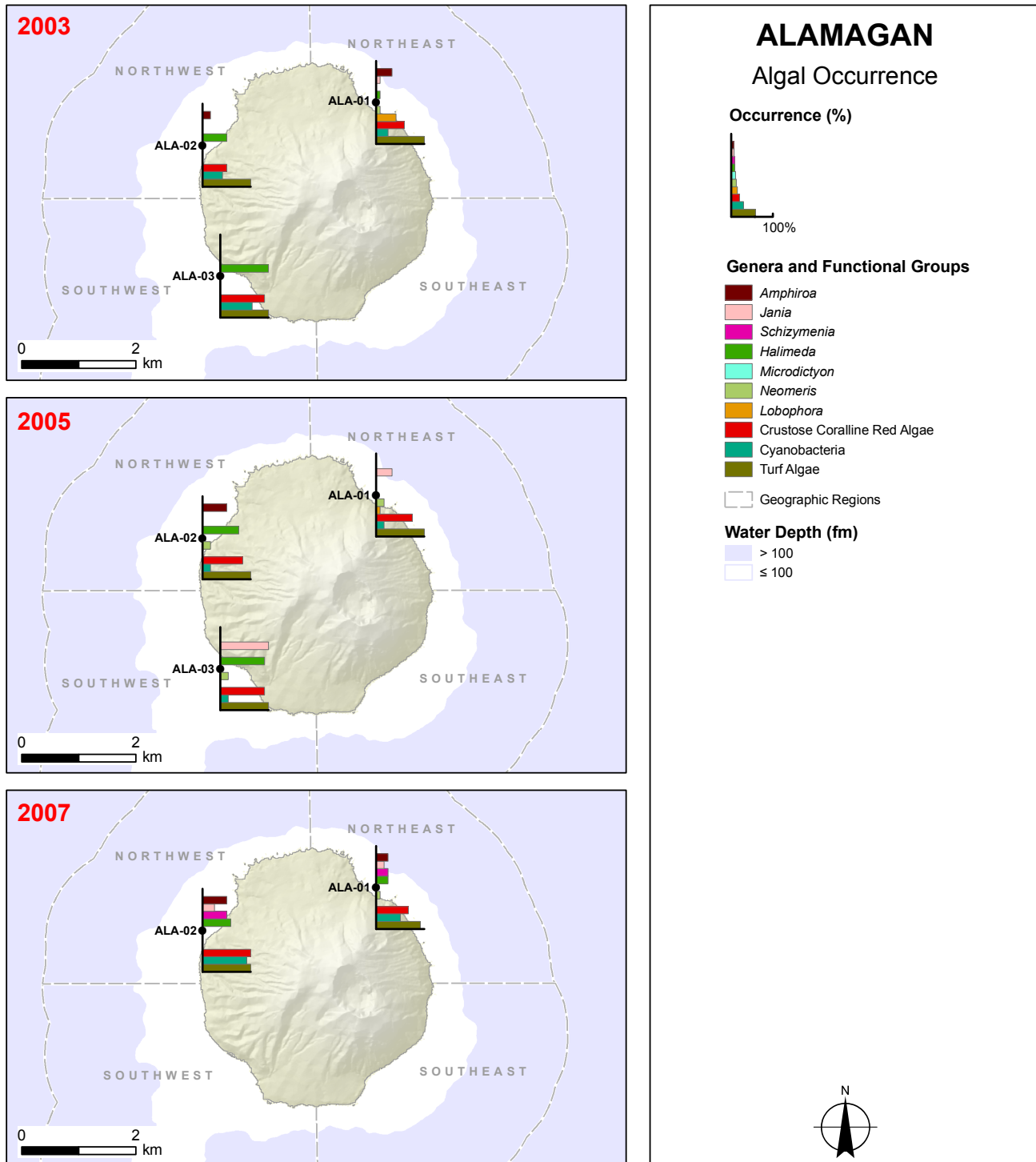


Figure 12.6.1d. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys of forereef habitats conducted at Alamagan during MARAMP 2003, 2005, and 2007. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

Turf algae and crustose coralline red algae were both exceptionally common in 2005, occurring in 100% and 83.3% of photoquadrats sampled at Alamagan. Cyanobacteria, in contrast, were found only in 16.7% of sampled photoquadrats.

During MARAMP 2007, REA benthic surveys were conducted at 2 sites on forereef habitats at Alamagan. In the field, 12 macroalgal genera (5 red, 5 green, and 2 brown), containing at least 12 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. ALA-01 in the northeast region had the highest macroalgal generic diversity with 11 genera, containing 11 species, documented in the field. Observed macroalgal generic diversity was lower at the other site, ALA-02 in the southwest region, with 8 species representing 8 genera recorded.

Species of the genera *Asparagopsis* and *Halimeda* were common at both sites surveyed at Alamagan in 2007, occurring in 50% and 41.7% of sampled photoquadrats (Fig. 12.6.1d, bottom panel). Of the 12 species recorded, 7 were found at both sites surveyed in 2007. Since only 2 sites were surveyed and both fell in the northern regions, distinctive spatial patterns of distribution were difficult to determine for most macroalgae at Alamagan. *Asparagopsis* was the most abundant macroalgal genus, occurring in 58.3% and 41.7% of photoquadrats sampled at ALA-01 and ALA-02. The genus *Halimeda* also was fairly abundant, occurring in slightly more than twice as many sampled photoquadrats at ALA-02 (58.3%) than at ALA-01 (25%). A similar pattern of distribution was found for the red algal genera *Schizymenia* and *Amphiroa*, both occurring in 50% of sampled photoquadrats at ALA-02 but only half that amount at ALA-01. Another green algal genus, *Boodlea*, was recorded in 41.7% of sampled photoquadrats at ALA-02, but, at ALA-01, this genus was observed only in a single photoquadrat with an occurrence of 8.3%. Other species recorded in low abundance were from the genera *Bornetella*, *Caulerpa*, *Culteria*, *Dictyota*, *Jania*, *Neomeris*, and *Peyssonnelia*.

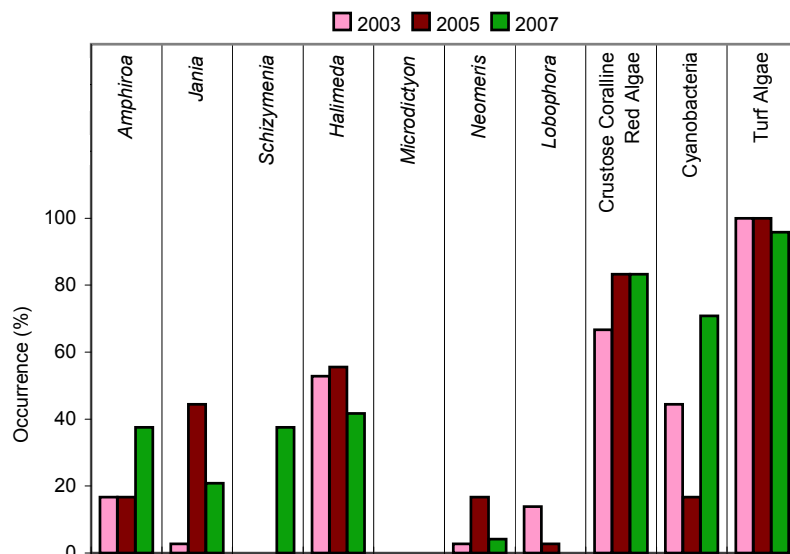
Turf algae, crustose coralline red algae, and cyanobacteria all were exceptionally common in 2007, occurring in 95.8%, 83.3%, and 70.8% of photoquadrats sampled at Alamagan (Fig. 12.6.1d, bottom panel). Turf algae and crustose coralline red algae both occurred in 100% of sampled photoquads at ALA-02 but in fewer photoquadrats (91.7% and 66.7%) sampled at ALA-01. Cyanobacteria were twice as common at ALA-02 than at ALA-01, where they were found in 91.7% and 50% of sampled photoquadrats.

The number of macroalgal genera recorded on forereef habitats at Alamagan increased from 9 genera during MARAMP 2003 to 12 genera during MARAMP 2005 and 2007, despite the fact that one less site was sampled in 2007 than in 2005 and 2003. Although 12 genera were observed in 2005 and 2007, the composition of the algal diversity is quite dissimilar between these MARAMP survey years. Difference in season and other factors likely can account for this difference in generic composition (for information on data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”). Further, it is likely that different seasonal flora were documented in 2005 and 2007 and that actual algal diversity over a given yearly cycle is greater than the 12 genera recorded both in 2005 and 2007.

Schizymenia, a red algal genus with obvious blade morphology, was not recorded at Alamagan in either 2003 or 2005 but in 2007 was found in 50% and 25% of photoquadrats sampled at ALA-01 and ALA-02 in the northeast and northwest regions. The genus *Boodlea*, found in 41.7% of sampled photoquadrats at ALA-02, is another example of previously unobserved alga appearing in relatively high abundance in 2007. Species of the genus *Halimeda* consistently had high occurrence values in the 3 survey years with overall sample means of 41.6%–55.6% (Fig. 12.6.1e). The occurrence of species of *Amphiroa* rose from 16.7% in 2003 and 2005 to 37.5% in 2007. Similarly, *Asparagopsis* was recorded in 8.3% of sampled photoquadrats in 2003 but in 50% of sampled photoquadrats in 2007. Additionally, the abundance of *Jania* varied between MARAMP survey periods, occurring in only 2.7% of photoquadrats sampled in 2003 but in 44% and 20.8% of sampled photoquadrats in 2005 and 2007.

Turf algae and crustose coralline red algae occurred in 95.8%–100% and 66.7%–83.3% of photoquadrats sampled at Alamagan during MARAMP 2003, 2005, and 2007. No patterns showing changes over time in the abundance of these functional groups were obvious.

Figure 12.6.1e. Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional group conducted on forereef habitats at Alamagan during MARAMP 2003, 2005 and 2007.



12.6.2 Surveys for Coralline-algal Disease

During MARAMP 2007, REA benthic surveys for coralline-algal disease were conducted in concert with coral disease assessments at 3 sites on forereef habitats at Alamagan. These surveys covered a total reef area of ~ 900 m². No cases of coralline-algal disease were detected.

12.7 Benthic Macroinvertebrates

12.7.1 Benthic Macroinvertebrates Surveys

Four groups of benthic macroinvertebrates—sea urchins, sea cucumbers, giant clams, and crown-of-thorns seastars (COTS)—were monitored on forereef habitats around the island of Alamagan through REA and towed-diver benthic surveys during MARAMP 2003, 2005, and 2007. This section describes by group the results of these surveys. A list of additional taxa observed during REA invertebrate surveys is provided in Chapter 3: “Archipelagic Comparisons.”

Monitoring these 4 groups of ecologically and economically important taxa provides insight into the population distribution, community structure, and habitats of the coral reef ecosystems of the Mariana Archipelago. High densities of the corallivorous COTS can affect greatly the community structure of reef ecosystems. Giant clams are filter feeders that are sought after in the Indo-Pacific for their meat, which is considered a delicacy, and for their shells. Sea cucumbers, sand-producing detritus foragers, are harvested for food. Sea urchins are important algal grazers and bioeroders.

During each of the 3 MARAMP survey years, 3 REA benthic surveys and 6 towed-diver surveys were conducted around Alamagan. When considering survey results from towed-diver surveys, keep in mind that cryptic or small organisms can be difficult for divers to see, so the density values presented in this report, especially of giant clams and sea urchins, may under-represent the number of individuals present.

Overall, both REA and towed-diver surveys revealed low daytime macroinvertebrate abundance on forereef habitats around Alamagan, compared to the rest of the Mariana Archipelago. Minor fluctuations in densities between MARAMP survey periods occurred with all target groups. Temporal patterns of islandwide mean macroinvertebrate density on forereef habitats around Alamagan—from towed-diver benthic surveys during MARAMP 2003, 2005, and 2007—are shown later in this section (Figs. 12.7.1b, d and f).

Giant Clams

During MARAMP 2003, species of *Tridacna* giant clams were observed at all 3 REA sites surveyed and in all of the 6 towed-diver surveys conducted around Alamagan. The overall mean density of giant clams from REA surveys was

3.67 organisms 100 m^{-2} (SE 1.20), and the islandwide mean density from towed-diver surveys was 0.07 organisms 100 m^{-2} (SE 0.01). Survey results suggest giant clams were most abundant at REA site ALA-03 in the southwest region with 6 organisms 100 m^{-2} (Fig. 12.7.1.a, top panel). Among all towed-diver surveys around this island, the 2 surveys completed in the western regions had the highest mean densities of giant clams with 0.12 and 0.1 organisms 100 m^{-2} ; segment densities from these surveys ranged from 0 to 0.58 organisms 100 m^{-2} .

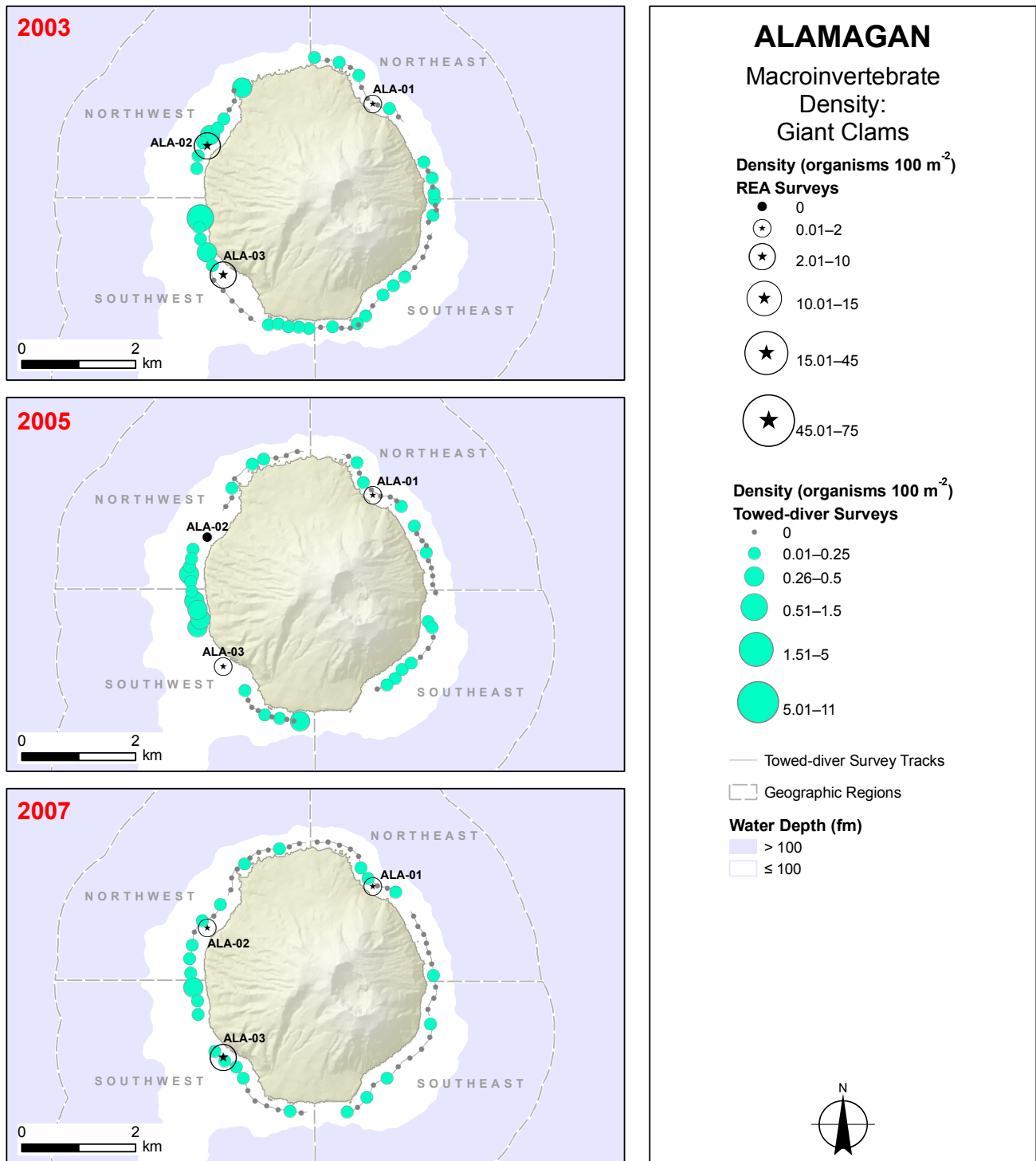


Figure 12.7.1a. Densities (organisms 100 m^{-2}) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Alamagan during MARAMP 2003, 2005, and 2007.

During MARAMP 2005, giant clams were observed at 2 of the 3 REA sites surveyed and in all 6 towed-diver surveys conducted around Alamagan. The overall mean density of giant clams from REA surveys was 1 organism 100 m^{-2} (SE 0.58), and the islandwide mean density from towed-diver surveys was 0.08 organisms 100 m^{-2} (SE 0.01). Survey results suggest giant clams were most abundant at ALA-02 in the northwest region with 2 organisms 100 m^{-2} (Fig. 12.7.1.a, middle panel). Among all towed-diver surveys around this island, the survey completed along the central western coast had the highest mean density of giant clams with 0.23 organisms 100 m^{-2} ; segment densities from this survey ranged from 0 to 0.38 organisms 100 m^{-2} . The second-greatest mean density of giant clams from a towed-diver survey was 0.08 organisms 100 m^{-2} , recorded in the southwest region; segment densities ranged from 0 to 0.34 organisms 100 m^{-2} .

During MARAMP 2007, giant clams were observed at all 3 REA sites surveyed and in all 6 towed-diver surveys conducted around Alamagan. The overall mean density of giant clams from REA surveys was 1.22 organisms 100 m^{-2} (SE 0.73), and the islandwide mean density from towed-diver surveys was 0.03 organisms 100 m^{-2} (SE 0.01). Survey results suggest giant clams were most abundant at ALA-03 in the southwest region with 2.67 organisms 100 m^{-2} (Fig. 12.7.1a, bottom panel). Among all towed-diver surveys around this island, the survey completed along the central western coast had the highest mean density of giant clams with 0.08 organisms 100 m^{-2} ; segment densities from this survey ranged from 0 to 0.28 organisms 100 m^{-2} .

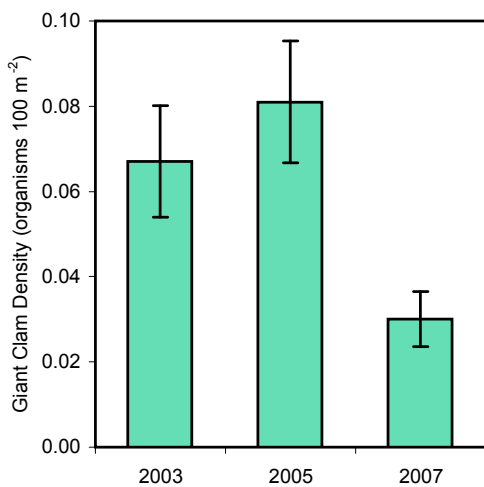


Figure 12.7.1b. Temporal comparison of giant clam mean densities (organisms 100 m^{-2}) from towed-diver benthic surveys conducted on forereef habitats around Alamagan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error ($\pm 1\text{ SE}$) of the mean.

Towed-diver surveys suggested low abundance of giant clams around Alamagan during the 3 MARAMP survey periods, relative to the rest of the Mariana Archipelago (Fig. 12.7.1b). Although densities were low, during each of the 3 survey years, the highest densities of giant clams resided along the western shore of this island. Minor fluctuations in density were observed, but this variation is not necessarily indicative of changes in the population structure of giant clams (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

Crown-of-thorns Seastars (COTS)

During MARAMP 2003, 2005, and 2007, no crown-of-thorns seastars (*Acanthaster planci*) were observed at the 3 REA sites surveyed or in the 6 towed-diver surveys conducted around Alamagan.

Sea Cucumbers

During MARAMP 2003, no sea cucumbers were observed at the 3 REA sites surveyed around Alamagan, but 4 of the 6 towed-diver surveys had recordings of sea cucumbers with an islandwide mean density of 0.006 organisms 100 m^{-2} (SE 0.003). Among all towed-diver surveys around this island, the survey completed in the southwest region had the highest mean density of sea cucumbers with 0.02 organisms 100 m^{-2} ; segment densities from this survey ranged from 0 to 0.09 organisms 100 m^{-2} (Fig. 12.7.1c, top panel).

During MARAMP 2005, again no sea cucumbers were observed at the 3 REA sites surveyed around Alamagan, but 3 of the 6 towed-diver surveys had recordings of sea cucumbers with an islandwide mean density of 0.012 organisms 100 m^{-2} (SE 0.004). Consistent with results from 2003, the towed-diver survey completed in the southwest region had the highest mean density of sea cucumbers with 0.03 organisms 100 m^{-2} ; segment densities from this survey ranged from 0 to 0.08 organisms 100 m^{-2} (Fig. 12.7.1c, middle panel).

2003

NORTHWEST NORTHWEST NORTHWEST NORTHWEST

ALA-01 ALA-02 ALA-03

SOUTHWEST SOUTHWEST SOUTHWEST SOUTHWEST

0 2 km

2005

NORTHWEST NORTHWEST NORTHWEST NORTHWEST

ALA-01 ALA-02 ALA-03

SOUTHWEST SOUTHWEST SOUTHWEST SOUTHWEST

0 2 km

2007

NORTHWEST NORTHWEST NORTHWEST NORTHWEST

ALA-01 ALA-02 ALA-03

SOUTHWEST SOUTHWEST SOUTHWEST SOUTHWEST

0 2 km

ALAMAGAN

Macroinvertebrate Density:
Sea Cucumbers

Density (organisms 100 m⁻²)

REA Surveys

- 0
- 0.01–1
- 1.01–5
- 5.01–10
- 10.01–15
- 15.01–60

Density (organisms 100 m⁻²)

Towed-diver Surveys

- 0
- 0.01–0.5
- 0.51–1
- 1.01–3
- 3.01–7
- 7.01–25

— Towed-diver Survey Tracks

Geographic Regions

Water Depth (fm)

- > 100
- ≤ 100

N

Figure 12.7.1c. Densities (organisms 100 m⁻²) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Alamagan during MARAMP 2003, 2005, and 2007.

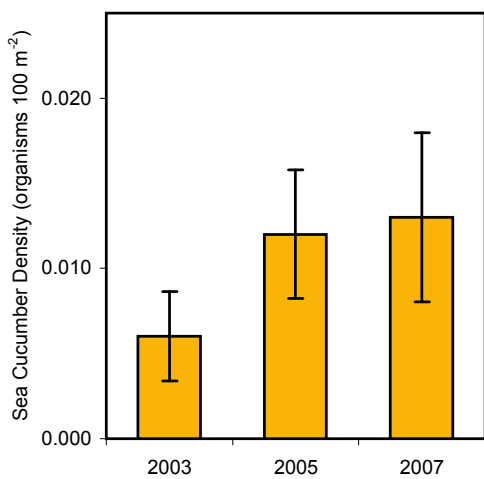


Figure 12.7.1d. Temporal comparison of mean densities (organisms 100 m⁻²) of sea cucumbers from towed-diver benthic surveys conducted on forereef habitats around Alamagan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Towed-diver surveys suggested low daytime abundance of sea cucumbers around Alamagan during MARAMP 2003, 2005, and 2007, relative to the rest of the Mariana Archipelago (Fig. 12.7.1d). Minor fluctuations in density were observed, but this variation is not necessarily indicative of changes in the population structure of sea cucumbers (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

Sea Urchins

During MARAMP 2003, sea urchins were observed at all 3 REA sites surveyed and in 5 of the 6 towed-diver surveys conducted around Alamagan (Fig. 12.7.1e, top panel). The overall mean density of sea urchins from REA surveys was 63.67 organisms 100 m⁻² (SE 19.77), and the islandwide mean density from towed-diver surveys was 0.64 organisms 100 m⁻² (SE 0.37). Survey results suggest that sea urchins were most abundant at ALA-02 in the northwest region with a mean density of 100 organisms 100 m⁻². All observations were of the rock-boring genus *Echinostrephus*. *Echinostrephus* also was the dominant urchin at ALA-03 and ALA-01. The highest diversity was found at ALA-01, with 3 urchin genera: *Echinostrephus*, *Echinothrix*, and *Echinometra*. Overall, 95% of the urchins observed were from the genus *Echinostrephus*.

Among all towed-diver surveys conducted around Alamagan in 2003, the survey completed in the southwest region had the highest mean density of sea urchins at 2.81 organisms 100 m⁻²; segment densities from this survey ranged from 0 to 19.93 organisms 100 m⁻². The second-greatest mean density from a towed-diver survey was 0.83 organisms 100 m⁻², recorded in the northwest region; segment densities ranged from 0 to 8.23 organisms 100 m⁻².

During MARAMP 2005, sea urchins were observed at 1 of the 3 REA sites surveyed and in 5 of the 6 towed-diver surveys conducted around Alamagan. In the northeast region, ALA-01 had a density of 7 organism 100 m⁻². The genera *Echinostrephus*, *Echinometra*, and *Echinothrix* were observed, with 57% of the urchins observed from the genus *Echinothrix*. The islandwide mean density of sea urchins from towed-diver surveys was 0.26 organisms 100 m⁻² (SE 0.11). Among all towed-diver surveys conducted around Alamagan, the survey completed in the northeast region had the highest mean density of 1.14 organisms 100 m⁻²; segment densities from this survey ranged from 0 to 5.46 organisms 100 m⁻² (Fig. 12.7.1e, middle panel).

During MARAMP 2007, sea urchins were observed at all 3 REA sites surveyed and in all 6 towed-diver surveys conducted around Alamagan. The overall mean density of sea urchins from REA surveys was 9.33 organisms 100 m⁻² (SE 7.83), and the islandwide mean density from towed-diver surveys was 0.03 organisms 100 m⁻². Survey results suggest that sea urchins were most abundant at ALA-02 in the northwest region with a mean density of 25 organisms 100 m⁻² (Fig. 12.7.1e, bottom panel). All observed urchins at REA sites were of the genus *Echinostrephus*. Among all towed-diver surveys around this island, the surveys completed along the northern part of Alamagan and in the southeast region had the highest mean densities of 0.05 and 0.04 organisms 100 m⁻²; segment densities from these surveys ranged from 0 to 0.43 organisms 100 m⁻².

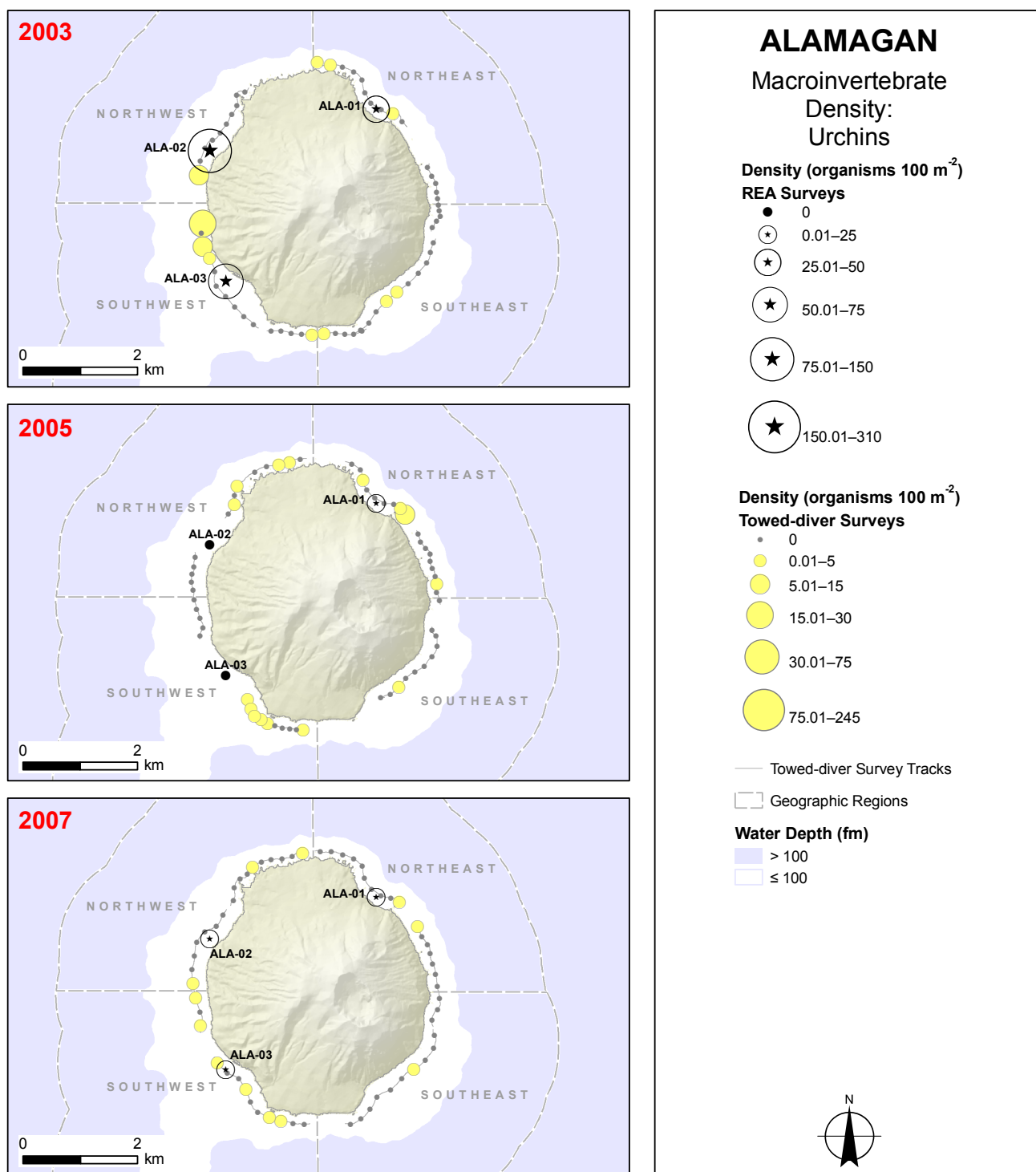


Figure 12.7.1e. Densities (organisms 100 m⁻²) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Alamagan during MARAMP 2003, 2005, and 2007.

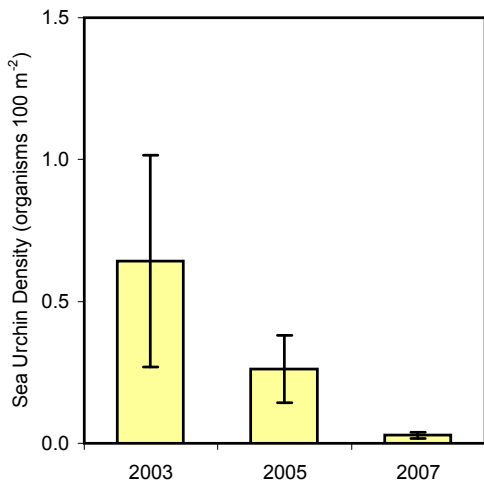


Figure 12.7.1f. Temporal comparison of mean densities (organisms 100 m⁻²) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Alamagan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Towed-diver surveys suggested extremely low daytime abundance of sea urchins around Alamagan during MARAMP 2003, 2005, and 2007, relative to the rest of the Mariana Archipelago (Fig. 12.7.1f). Minor fluctuations in density were observed, but this variation is not necessarily indicative of changes in the population structure of sea urchins (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

12.8 Reef Fishes

12.8.1 Reef Fish Surveys

Large-fish Biomass

During MARAMP 2003, 6 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted in forereef habitats around the island of Alamagan. The overall estimated mean biomass of large fishes around this island, calculated as weight per unit area, was 1.06 kg 100 m⁻² (SE 0.13). Observed large-fish biomass was highest in the northeast region, where sharks and snappers were abundant (Fig. 12.8.1a, top panel). Nurse sharks (Ginglymostomatidae), reef sharks (Carcharhinidae), and snappers (Lutjanidae) together contributed the greatest proportion (70%) or 0.75 kg 100 m⁻² of overall mean large-fish biomass. Of those families, the tawny nurse shark (*Nebrius ferrugineus*) and grey reef shark (*Carcharhinus amblyrhynchos*) were the most abundant species, accounting for 0.19 kg 100 m⁻² and 0.17 kg 100 m⁻² of overall mean biomass of large fishes. Snappers contributed 32% of overall mean large-fish biomass, and the twinspot snapper (*Lutjanus bohar*) was the dominant snapper species by biomass.

During MARAMP 2005, 6 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Alamagan. The overall estimated mean biomass of large fishes around this island was 0.93 kg 100 m⁻² (SE 0.10). Observed large-fish biomass was distributed fairly evenly around this island (Fig. 12.8.1a, middle panel). Reef sharks contributed the greatest proportion (57%) or 0.52 kg 100 m⁻² to overall mean large-fish biomass. The whitetip reef shark (*Triaenodon obesus*) was the largest contributor, accounting for 0.28 kg 100 m⁻² of large-fish biomass, and grey reef sharks contributed 0.25 kg 100 m⁻² of overall mean large-fish biomass. Parrotfishes (Scaridae) also were observed regularly, contributing 13% to overall mean large-fish biomass. The ember parrotfish (*Scarus rubroviolaceus*) was the most abundant parrotfish species, contributing 0.09 kg 100 m⁻² to parrotfish biomass. Of note was a single sighting of a humphead wrasse (*Cheilinus undulatus*) during a survey in the northwest region.

During MARAMP 2007, 6 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Alamagan. The overall estimated mean biomass of large fishes was 0.70 kg 100 m⁻² (SE 0.15). Observed large-fish biomass was highest in the western regions, where sharks were common (Fig. 12.8.1a, bottom panel). Reef sharks and nurse sharks contributed more than any other group, together accounting for 42 % or 0.29 kg 100 m⁻² of overall mean large-fish biomass. The whitetip reef shark and tawny nurse shark were the largest contributors to overall mean large-fish biomass with 0.11 and 0.14 kg 100 m⁻², respectively. Snappers and surgeonfishes (Acanthuridae) also were common during this survey period. The twinspot snapper alone accounted for 20% of overall mean biomass of large fishes, and the sleek surgeonfish (*Naso hexacanthus*) contributed 16% of overall mean large-fish biomass.

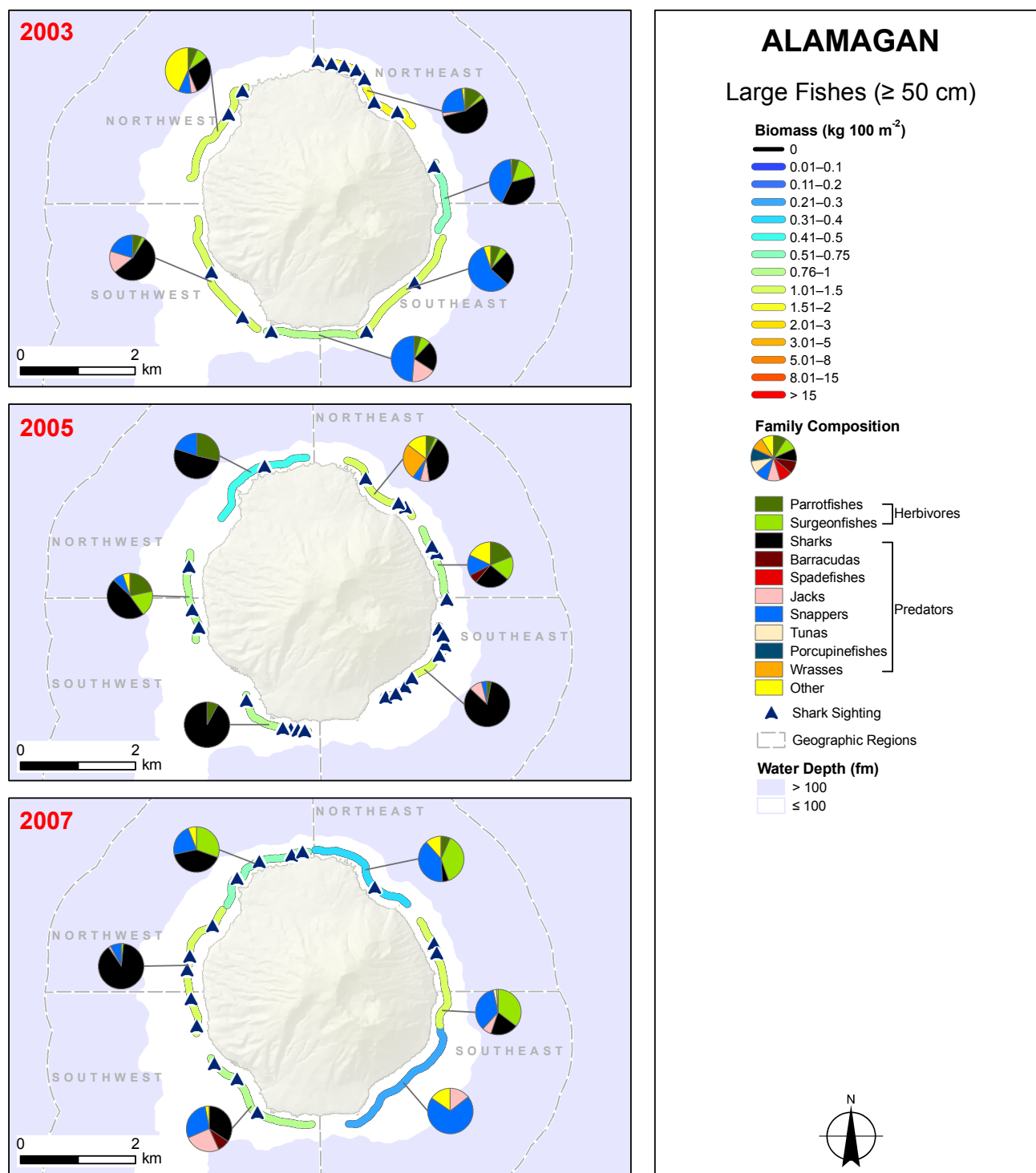
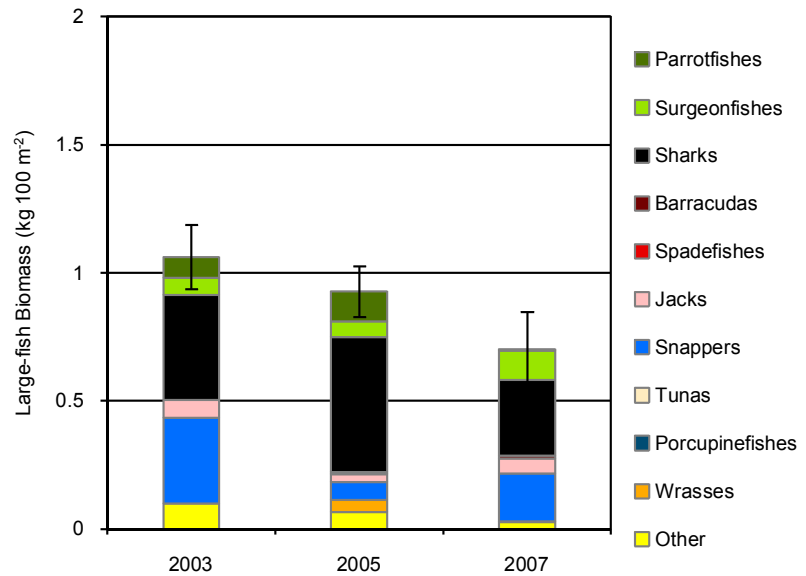


Figure 12.8.1a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m⁻²), family composition, and shark sightings from towed-diver fish surveys of forereef habitats conducted around Alamagan during MARAMP 2003, 2005, and 2007. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

Large-fish biomass from towed-diver surveys of forereef habitats did not show any clear temporal patterns and was generally around the average for the unpopulated northern islands in the Mariana Archipelago, varying between 1.06 kg 100 m⁻² in 2003 and 0.70 kg 100 m⁻² in 2007 (Fig. 12.8.1b). Reef sharks and nurse sharks were common during each of the 3 MARAMP years and contributed an average of 46% of the overall estimated mean for large-fish biomass. The whitetip reef shark and tawny nurse shark were the most abundant shark species during MARAMP 2003 and 2005, and the grey reef shark was the most frequently encountered shark species during MARAMP 2007. Snappers also were common during each

Figure 12.8.1b. Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m⁻²) from towed-diver fish surveys conducted in forereef habitats around Alamagan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.



of the 3 MARAMP survey periods, with the twinspot snapper as the most abundant snapper species. Notable observations included a single sighting of the humphead wrasse in 2005 and sightings of the dogtooth tuna (*Gymnosarda unicolor*) and black-margin barracuda (*Sphyræna genie*) in 2007.

Total Fish Biomass and Species Richness

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Alamagan during MARAMP 2003 was moderate compared to other sites in the Mariana Archipelago, with an overall sample mean of 5.75 kg 100 m⁻² (SE 0.59). The highest biomass of 6.50 kg 100 m⁻² was observed at REA site ALA-02 in the northwest region, where surgeonfishes, triggerfishes (Balistidae), and snappers were common (Fig. 12.8.1c, top panel). No sharks were observed during this survey period. Surgeonfishes, parrotfishes, and triggerfishes contributed the greatest proportions to total fish biomass: 22%, 15%, and 14%. The orangespine unicornfish (*Naso lituratus*) was the dominant surgeonfish (0.35 kg 100 m⁻²), and the pinktail triggerfish (*Melichthys vidua*) was the dominant triggerfish (0.50 kg 100 m⁻²). Nearly all parrotfish biomass was split almost equally between Forsten's parrotfish (*Scarus forsteni*) and the ember parrotfish (*S. rubroviolaceus*).

Based on REA surveys conducted during MARAMP 2003, species richness at Alamagan was moderately high with a range of 42–47 species 100 m⁻². The highest diversity was found at ALA-03 in the southwest region (Fig. 12.8.1c, top panel). Wrasses (Labridae), damselfishes (Pomacentridae) and surgeonfishes were the most diverse families, with 21, 14, and 13 species recorded in 2003. Surgeonfishes were the most abundant taxa, and the orangespine unicornfish dominated counts with 112 individuals 100 m⁻² observed. Damselfishes were the second-most abundant taxa, and the Vanderbilt's chromis (*Chromis vanderbilti*) was the most common species with 94 individuals 100 m⁻² recorded. The ornate wrasse (*Halichoeres ornatus*) was the most abundant wrasse species.

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Alamagan during MARAMP 2005 was high compared to other sites in the Mariana Archipelago, with an overall sample mean of 16.80 kg 100 m⁻² (SE 10.35). The highest biomass of 37.33 kg 100 m⁻² was observed at ALA-03 in the southwest region, where 3 humphead wrasse and a tawny nurse shark were observed (Fig. 12.8.1c, middle panel). Wrasses contributed the greatest proportion (54%) or 9.13 kg 100 m⁻² of the total fish biomass. Reef sharks and surgeonfishes contributed 10% and 9%, respectively, to total fish biomass. The humphead wrasse accounted for over 97% of wrasse biomass. Two sharks were observed during the survey period, a whitetip reef shark and a tawny nurse shark.

Based on REA surveys conducted during MARAMP 2005, species richness at Alamagan was moderate with a range of 27–33 species 100 m⁻². The highest species richness was found at ALA-01 in the northeast region (Fig. 12.8.1c, middle panel). Consistent with observations made during MARAMP 2003, wrasses, damselfishes, and surgeonfishes were the most diverse families with 18, 13 and 13 species recorded. The ornate wrasse was the most abundant wrasse species with 22 individuals 100 m⁻² observed, while the brown surgeonfish (*Acanthurus nigrofusus*) was the most abundant surgeonfish species with 8 individuals 100 m⁻² observed. Damselfishes were the most abundant fish taxa overall, and the midget chromis (*Chromis acares*) dominated counts with 127 individuals 100 m⁻² recorded at Alamagan.

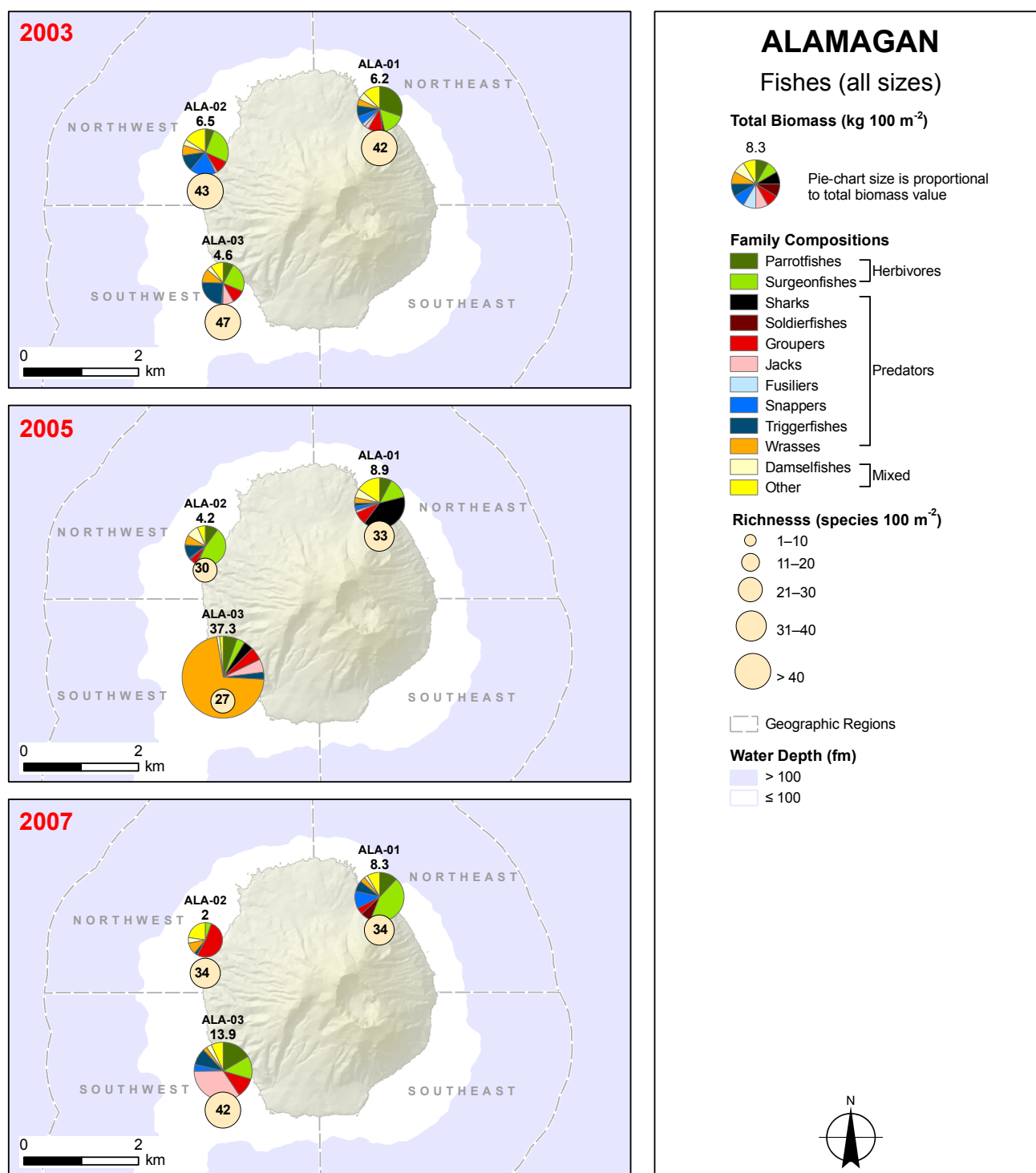


Figure 12.8.1c. Observations of total fish biomass (all species and size classes in kg 100 m⁻²), family composition, and species richness (species 100 m⁻²) from REA fish surveys using the belt-transect method in forereef habitats at Alamagan during MARAMP 2003, 2005, and 2007.

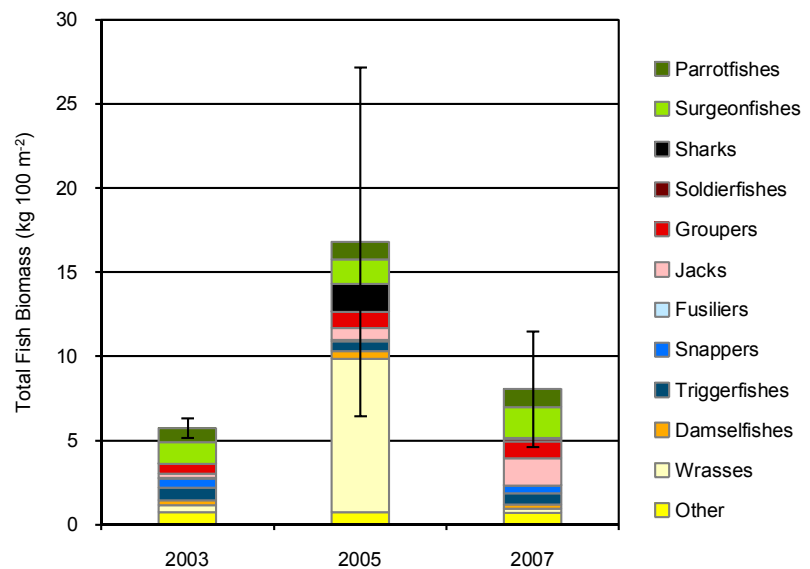
Total fish biomass for the 3 REA sites surveyed in forereef habitats at Alamagan during MARAMP 2007 was moderate compared to other sites in the Mariana Archipelago, with an overall sample mean of 8.06 kg 100 m⁻² (SE 3.44). The highest fish biomass of 13.92 kg 100 m⁻² was found at ALA-03, where a school of bigeye trevally (*Caranx sexfaciatus*) was observed (Fig. 12.8.1c, bottom panel). Surgeonfishes and jacks contributed the greatest proportions (23% and 20%) of total fish biomass. The bluespine unicornfish (*Naso unicornis*), brown surgeonfish, and orangespot surgeonfish (*Acanthurus olivaceus*) dominated surgeonfish biomass with 0.47, 0.43, and 0.34 kg 100 m⁻². The bigeye trevally accounted for the greatest proportion (77%) or 1.25 kg 100 m⁻² of jack biomass.

Based on REA surveys conducted during MARAMP 2007, species richness at Alamagan was moderate with a range of 34–42 species 100 m^{-2} . The highest diversity was observed at ALA-03 in the southwest (Fig. 12.8.1c, bottom panel). Consistent with survey results from 2003 and 2005, wrasses, surgeonfishes, and damselfishes were the most diverse families with 21, 15, and 14 species observed. The ornate wrasse was the most abundant wrasse species, while the brown surgeonfish was the most abundant surgeonfish species. Damselfishes again were the most abundant fish taxa overall, and the midget chromis dominated counts with 179 individuals 100 m^{-2} .

No clear spatial pattern was evident for total fish biomass at Alamagan between the 3 MARAMP survey periods; however, ALA-03 in the southwest region had the highest mean total fish biomass for surveys conducted in 2005 and 2007. Additionally, no clear temporal patterns were observed during the 3 survey periods (Fig. 12.8.1d), but the highest overall mean total fish biomass of $16.80\text{ kg } 100\text{ m}^{-2}$ was recorded in 2005, when 3 humphead wrasse were observed at ALA-03. A similarly high biomass estimate was recorded for ALA-03 in 2007, when a school of bigeye trevally was observed. Surgeonfishes also were common, but no single species consistently dominated counts during the 3 survey periods.

Species richness was relatively uniform at Alamagan in each of the 3 MARAMP surveys years and ranged from 27–47 species 100 m^{-2} . Consistent with survey results at other islands in the Mariana Archipelago, wrasses, damselfishes, and surgeonfishes were the most diverse families, with an average of 20, 14 and 14 species recorded. Damselfishes dominated counts, with the Vanderbilt's chromis and midget chromis as the most abundant damselfish species.

Figure 12.8.1d. Temporal comparison of mean values of total fish biomass (all species and size classes in $\text{kg } 100\text{ m}^{-2}$) from REA fish surveys of forereef habitats conducted at Alamagan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error ($\pm 1\text{ SE}$) of the mean.



12.9 Marine Debris

12.9.1 Marine Debris Surveys

During MARAMP 2003 and 2007, no marine debris was observed during the 6 towed-diver surveys of forereef habitats conducted around the island of Alamagan (Fig. 12.9.1a, top and bottom panel). During MARAMP 2005, 1 sighting of derelict fishing gear was recorded in the 6 towed-diver surveys conducted around this island (Fig. 12.9.1a, middle panel). Monofilament line was observed in the southwest region. No munitions, wrecks, or other man-made objects were identified during the 3 MARAMP survey years.

Observations of debris are positive identifications, but absence of reports does not imply lack of debris. Since methods for observing marine debris varied between MARAMP surveys in 2003, 2005, and 2007, temporal comparisons are not appropriate. Debris sightings were recorded differently—with sightings in 2003 recorded as a direct part of diver observational methods and sightings in 2005 and 2007 recorded solely as incidental observations by towed divers in their observer comments.

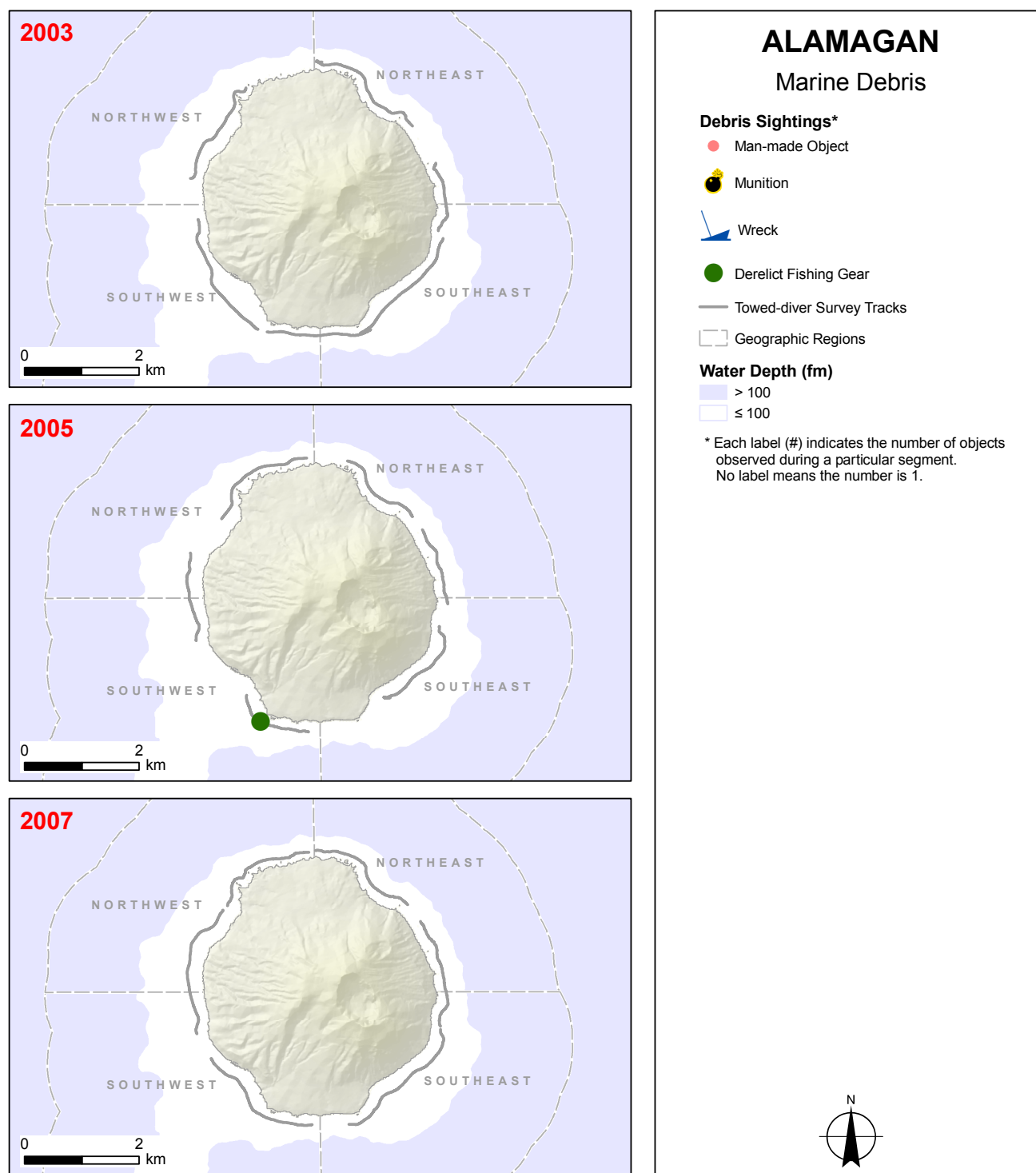


Figure 12.9.1a. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Alamagan during MARAMP 2003, 2005, 2007. No debris sites were identified in 2003 and 2007. Symbols indicate the presence of specific debris types.

12.10 Ecosystem Integration

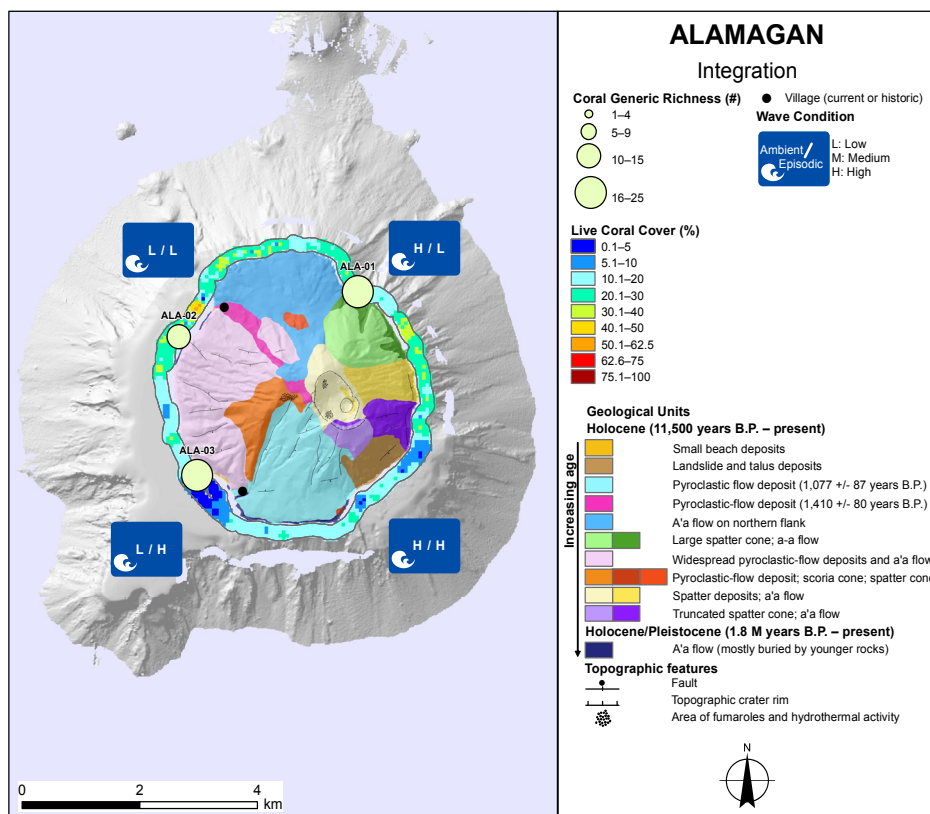
The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Alamagan are discussed in the discipline-specific sections of this chapter. In this section, key ecological and environmental aspects are considered concurrently to identify potential relationships between various ecosystem components. In addition to this island-level analysis, evaluations across the entire Mariana Archipelago are presented in Chapter 3: “Archipelagic Comparisons,” including archipelago-wide reef condition indices with ranks for Alamagan as well as the other 13 islands covered in this report.

North and northeast of Alamagan, the submarine topography is characterized by steep-sided, narrow ridges and channels that radiate out from this island. The submarine ridges in the northeast region of Alamagan are particularly pronounced, matched by steep slopes onshore (Fig. 12.1.2a in Section 12.1.2: “Geography”), and adjacent to older volcanic strata associated with the main crater and a large spatter cone (Fig. 12.1.2b). Around the northern side of Alamagan, which has been affected by lava flow, submarine ridges are less pronounced. This gently sloping lava platform extends this island’s coastline northward and can be distinguished on the slope map as an area of low slopes north of this island (Fig. 12.1.2a). The seascape found north and northeast of Alamagan is shaped by not only these steep-sided ridges but also numerous boulders that litter the seabed and create holes and crevices, resulting in the highest habitat complexity observed around Alamagan (Fig. 12.3.3a in Section 12.3.3: “Habitat Characterization”). As observed during towed-diver surveys, these ridges ran from shallow waters and ended in deep drop-offs. The substrate in this area, based on towed-diver surveys, was predominantly hard with a small amount of sand present between boulders (Fig. 12.3.3a) and supported live-hard-coral cover primarily of 10.1%–40% throughout this area (Fig. 12.10a).

The rest of Alamagan—the southwest and southeast regions and the southern part of northwest region—can be divided into 4 areas, with different volcanic and numerous physical factors influencing the benthic communities in each of them.

On the west side of Alamagan, the onshore topography is characterized by deep ravines. This area has some of the oldest volcanic strata, and the landscape has been shaped by erosion (Fig. 12.10a). In the shallow waters around the southern part of the northwest region and the northern part of the southwest region, the seascape is dominated by an extensive shelf area of hard substrate covered in place with surface sand. For most segments of the towed-diver surveys completed across this shelf, cover of live corals was moderately low with 1.1%–30%, compared to results from other islands surveyed in

Figure 12.10a. Cover (%) observations of live hard corals from towed-diver benthic surveys and generic richness from REA benthic surveys conducted around Alamagan during MARAMP 2003, 2005 and 2007. Values of coral cover represent interpolated values from the 3 survey years, and generic richness values represent averages of data from the 3 survey years. Color-coded areas on the island indicate different geologic units. A large, blue icon indicates the level of ambient and episodic wave exposure for each geographic region. Underlying these data in grey scale is the hillshade bathymetry.



the Mariana Archipelago (Fig. 12.10a). The lowest level of live coral cover on this shelf was observed in areas covered by sand. Still, the highest live coral cover found around Alamagan was observed in the northwest region. In a 200-m stretch close to the edge of this shelf, abundant coral colonies of the genus *Porites* resulted in live coral cover of 40.1%–62.5% (Figs. 12.10a and b).

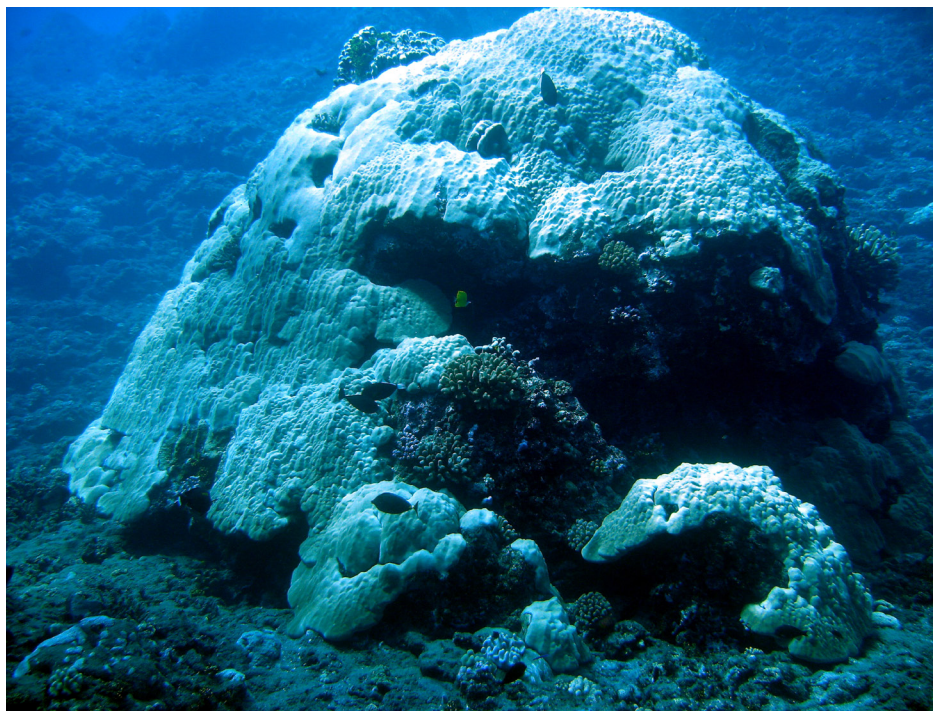


Figure 12.10b. A large colony of corals of the genus *Porites* at Alamagan. NOAA photo by Robert Schroeder

On the east side of Alamagan, onshore geology is composed of a similarly old volcanic unit in the form of a truncated spatter cone and an associated fragmented, rough, spiky lava flow. However, in contrast to west Alamagan, the volcanic strata in this area are covered with more recent landslide deposits (Fig. 12.10a), contributing to the complex texture shown by the bathymetry and derived products for this area (see Fig. 12.3.1c and other maps in Section 12.3.1: “Acoustic Mapping”). Results from towed-diver surveys suggested a habitat of medium-low to medium-high complexity, consisting of mostly boulders interspersed with sand presumably derived from landslide deposits. The boulders were colonized by encrusting corals. In the southeast region, towed-diver surveys showed that coral cover (< 20%) and macroalgal cover in 2005 and 2007 was low compared to results from other areas surveyed around Alamagan (Fig. 12.10a; Fig. 12.6.1a in Section 12.6.1: “Algal Surveys”).

South of Alamagan, the seascape is heavily influenced by a pyroclastic flow deposit that occurred at ~ AD 870. This flow was responsible for the gentle slopes observed on the southern part of this island (Fig. 12.1.2a in Section 12.1.2: “Geography”). A deep graben, which is a block of rock that lies between 2 faults and has moved downward to form a depression, constrained this flow in this area and channeled it in a southwest direction (Fig. 12.1.2b) before it fanned out and extended Alamagan’s coastline. This island’s seascapes were similarly affected by this flow. The absence of a shallow shelf in this area may be a result of this pyroclastic flow overtopping the shelf that was observed in other areas around Alamagan. The flow in this area resulted in a seabed characterized by steep slopes at depths ≥ 30 m (Fig. 12.3.1c in Section 12.3.1: “Acoustic Mapping”). In this area, habitat complexity ranged from medium-low to medium and live coral cover was low (< 20%) over most survey segments. Macroalgae were a more dominant component of the substrate in this area, with macroalgal cover of 10.1%–62.5% (Fig. 12.6.1a in Section 12.6.1: “Algal Surveys”). Towed-diver surveys described habitats as rolling reef ending at a steep drop-off, and the location of survey tracks suggested that this rolling reef may have occurred on the edge of a very narrow shelf. This edge is just shown on the bathymetry and slope maps for Alamagan (Figs. 12.3.1b and c in Section 12.3.1: “Acoustic Mapping”), and this narrow shelf is perhaps all that remains of a larger shelf that has been covered by the pyroclastic flow deposits described previously.

The overall estimated biomass of large fishes around Alamagan, based on towed-diver surveys, was comparable to the biomass found around most other northern islands in the Mariana Archipelago and higher than the biomass recorded around the neighboring islands of Pagan, Guguan, and Sarigan across the 3 MARAMP survey periods. The greatest contribution

to large-fish biomass around Alamagan came from reef sharks (Carcharhinidae; Fig. 12.10c) and nurse sharks (Ginglymostomatidae), both of which were regularly observed during the 3 survey years (Fig. 12.8.1a in Section 12.8.1: “Reef Fish Surveys”). Fish species richness was moderately high at Alamagan, ranging from 27–47 species per site across the 3 survey periods, compared to levels seen at other areas in the Mariana Archipelago (Fig. 12.8.1c in Section 12.8.1: “Reef Fish Surveys”). The diversity of the fish community at Alamagan may result from the relative isolation of Alamagan, which is more than 250 km from Saipan, the nearest populated island.

Figure 12.10c. Whitetip reef shark (*Triaenodon obesus*) at Alamagan. NOAA photo by Robert Schroeder



12.11 Summary

MARAMP integrated ecosystem observations provide a broad range of information: bathymetry and geomorphology, oceanography and water quality, and biological observations of corals, algae, fishes, and benthic macroinvertebrates along the forereef habitats around Alamagan. Methodologies and their limitations are discussed in detail in Chapter 2: “Methods and Operational Background,” and specific limitations of the data or analyses presented in this Alamagan chapter are included in the appropriate discipline sections. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter. The conditions of the fish and benthic communities and the overall ecosystem around Alamagan, relative to all the other islands in the Mariana Archipelago, are discussed in Chapter 3: “Archipelagic Comparisons.”

This section presents an overview of the status of coral reef ecosystems around the island of Alamagan as well as some of the key natural processes and anthropogenic activities influencing these ecosystems:

- Alamagan is located in the middle of the Mariana Archipelago. With a land area of 12.96 km², this island is about one-tenth the size of Saipan.
- The highest point on this island is Bandeera Peak, formed by a deep crater and surrounded by steep slopes with flatter areas extending north and south as a result of lava flows. No beaches are found around Alamagan, and this island is surrounded by sea cliffs. The last known eruption at Alamagan was at ~ AD 870.
- Historically, small human populations have inhabited Alamagan, mainly within 2 villages. In 2000, a homestead site was observed on the northwestern side of this island. Populations are expected to increase in the future because legislation enacted in 2010 encourages repatriation of this island.

- Many steep-sided, narrow ridges incise the moderately steep submarine flanks observed north and northeast of Alamagan. Towed-diver surveys described these habitats as hard substrate of medium to high complexity with steep reef slopes, ridges, and boulders.
- Southeast of Alamagan, a small shelf is present and has a surface of complex texture, possibly indicating a spur-and-groove habitat. West of Alamagan, a more extensive shelf area is present at depths of 25–40 m. Southwest of Alamagan, a second, deep shelf is present at depths of 80–120 m. Towed-diver surveys revealed that habitats on the shelves south and southeast of Alamagan were of lower complexity and had higher sand cover than habitats observed farther north.
- Wave model output shows ambient trade wind swells impacting the northeast and southeast regions. Episodic wave energy from storm tracks impacts the southwest and the southeast regions.
- For the 3 REA sites surveyed at Alamagan during MARAMP 2007, the overall sample mean of live-hard-coral cover was 23.5%. Across the 3 MARAMP survey years, islandwide mean coral cover from towed-diver surveys was 17%–22%, a high level compared to values recorded at other islands in the Mariana Archipelago.
- At the 3 REA sites surveyed at Alamagan in 2007, 6 cases of coral disease were detected, resulting in an overall mean prevalence of 0.01%. The most numerically abundant disease state was bleaching, followed by subacute tissue loss and other syndromes, particularly infestation and overgrowth by species of the encrusting sponge *Terpios*. No signs of predation scars from crown-of-thorns seastars (*Acanthaster planci*) or corallivorous snails were documented at REA sites, and crown-of-thorns seastars have never been observed at Alamagan during MARAMP surveys.
- Giant clams were fairly common around Alamagan, but sea cucumber densities were extremely low during each of the 3 MARAMP survey years.
- Overall mean large-fish biomass around Alamagan, from towed-diver surveys, was close to the average values observed for the unpopulated, northern islands across the 3 MARAMP survey years. Biomass of large fishes around Alamagan varied from 1.06 100 m⁻² in 2003 to 0.70 100 m⁻² in 2007.
- Total fish biomass, based on REA surveys, was moderately high in each of the 3 survey periods, compared with levels observed in the rest of the Mariana Archipelago, and specifically in 2005 with a value of 16.80 kg 100 m⁻². The highest total fish biomass in 2005 and 2007 was found in the southwest region at ALA-03, where 3 humphead wrasses were recorded in 2005 and a large school of bigeye trevally was seen in 2007.

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